Energy, Mines and Resources Canada
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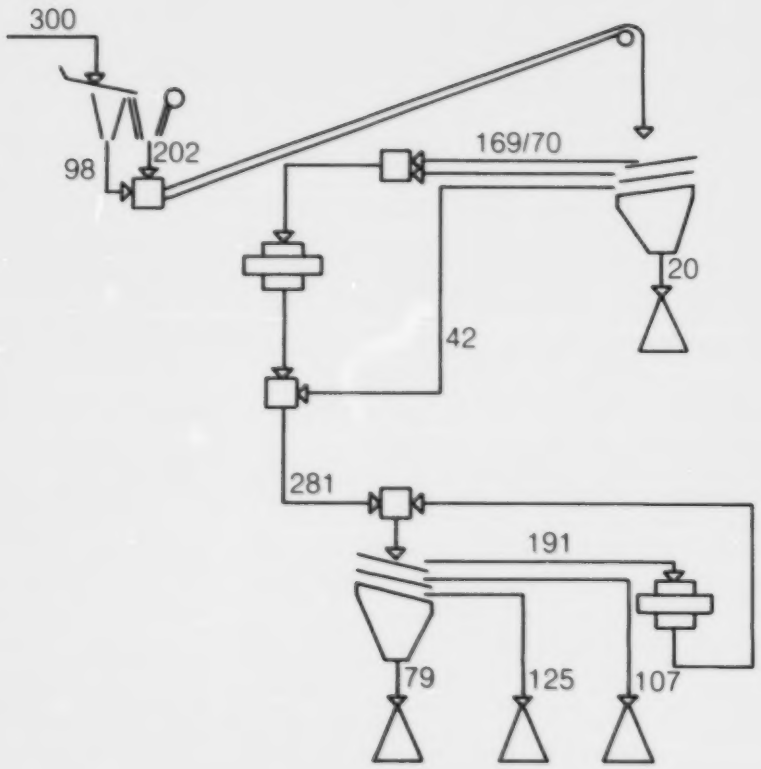
CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

MINERAL SCIENCES LABORATORIES ANNUAL REPORT 1987/88

APRIL 1988



Canada

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MINERAL SCIENCES LABORATORIES

ANNUAL REPORT 1987/88

CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY

ENERGY, MINES AND RESOURCES CANADA

DIVISION REPORT MSL 88-69 (TR)

MICROMEDIA

158 pp

FOREWORD

The Annual Report of the Mineral Sciences Laboratories for 1987/88 contains an overview of the accomplishments and activities of the division during this fiscal year. The preparation of an annual report enlists the good will and effort of the entire staff; special acknowledgement should go to Susan Lord and Lloyd Dalton who coordinated the report and to Lorna Paquette and Joan Villeneuve for technical and editorial endeavors.

New features which had been incorporated last year to provide a more detailed and comprehensive overview of the activities of the laboratories are continuing such as ongoing federal/provincial Mineral Development Agreement studies and significant contacts with industry, universities and various government agencies.

This annual report reflects some of the commitments which were reported in the CANMET Business Plan. In future, specific items will be highlighted to indicate new directions and also to reflect on accomplishments.

Comments from readers are welcome and should be directed to:

L.L. Sirois
Director
Mineral Sciences Laboratories

AVANT-PROPOS

Le rapport annuel des Laboratoires des sciences minérales pour l'année financiere 1987/88 donne un aperçu des activités et des réalisations de la Division durant cette période. La préparation du rapport annuel fait appel à la bonne volonté et à la participation de tout le personnel de la Division; nous désirons remercier tout spécialement Susan Lord et Lloyd Dalton qui ont coordonné la compilation du rapport et aussi Lorna Paquette et Joan Villeneuve pour leurs efforts techniques et éditoriaux.

Certains articles qui apparaissaient dans le rapport précédent et qui aidaient à mieux comprendre les détails des activités au sein des laboratoires seront poursuivis cette année. Ils traiteront entre autres des études en cours dans le cadre des Ententes fédérales/provinciales sur l'exploitation minérale; et des contacts importants avec l'industrie, les universités et les nombreuses agences governementales.

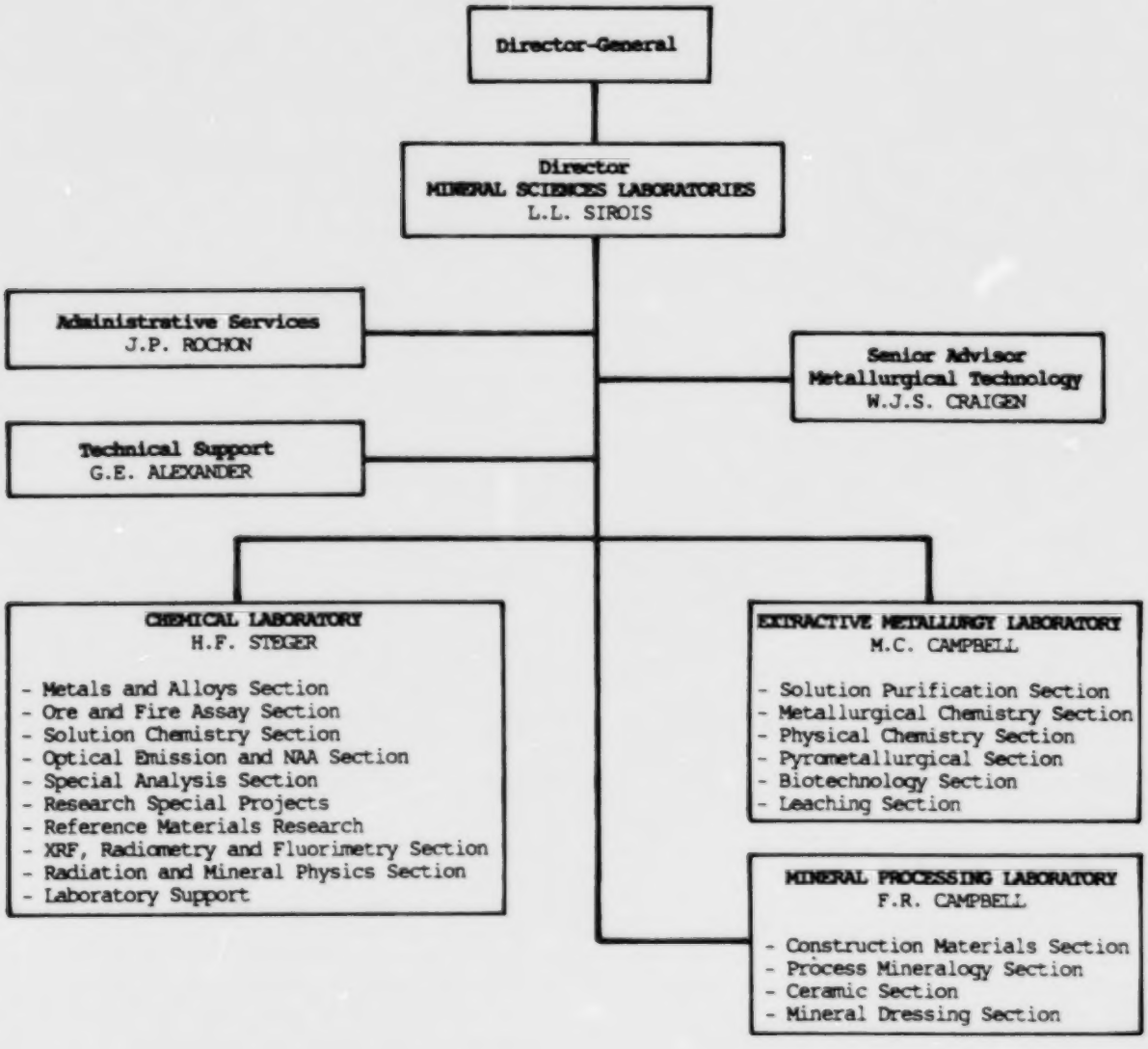
Nous invitons les lecteurs à nous faire parvenir leurs commentaires en les adressant à:

L.L. Sirois
Directeur
Laboratoires des sciences minérales

ORGANIZATION AND PROFESSIONAL STAFF

CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY (CANMET)

MINERAL SCIENCES LABORATORIES



DISTRIBUTION OF RESOURCES

MSL - FISCAL YEAR 1987-88

PROGRAM - MINERAL AND EARTH SCIENCES
ACTIVITY - "A-BASE

SUB-ACTIVITY	MSL $000's
20. COAL MINING AND PREPARATION	
- Personnel (PY)	263(5)
- Operating	75
- Capital	18
30. MINERAL PROCESSING	
- Personnel (PY)	8403(169)
- Operating	1233
- Capital	342
50. FUELS TECHNOLOGY	
- Personnel (PY)	47(1)
- Operating	20
- Capital	20
70. METALS AND MATERIALS	
- Personnel (PY)	144(3)
- Operating	10
- Capital	10
ACTIVITY TOTAL	
- Personnel (PY)	8857(179)
- Operating	1338
- Capital	390

PROGRAM - MINERAL AND EARTH SCIENCES
ACTIVITY - ENERGY R&D

SUB-ACTIVITY	MSL $000's
20. COAL MINING AND PREPARATION	
- Personnel (PY)	Nil
- Operating	Nil
- Capital	269
30. MINERAL PROCESSING	
- Personnel (PY)	250(5)
- Operating	335
- Capital	304
50. FUELS TECHNOLOGY	
- Personnel (PY)	50(1)
- Operating	20
- Capital	24
70. METALS AND MATERIALS	
- Personnel (PY)	Nil
- Operating	Nil
- Capital	Nil
ACTIVITY TOTAL	
- Personnel (PY)	300(6)
- Operating	355
- Capital	597

PROGRAM - MINERAL DEVELOPMENT AGREEMENT
ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	144(4)
- Operating	24
- Capital	Nil

PROGRAM - BIOTECHNOLOGY

ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	Nil
- Operating	25
- Capital	Nil

PROGRAM - ASBESTOS TECHNOLOGY
ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	Nil
- Operating	53
- Capital	Nil

HIGHLIGHTS

CHEMICAL LABORATORY

The Chemical Laboratory provides analytical support services for, and carries out research in analytical methodology for CANMET projects; provides consulting and technical assistance in analytical chemistry to other federal organizations and universities; provides the sole Canadian analytical umpire service for uranium determination in uranium concentrates; prepares, certifies and distributes reference materials to assist in quality control in the Canadian minerals processing industry; and participates in committee work for national and international organizations. The Laboratory also carried out research in, and provides support to CANMET projects and outside organizations for physical measurements in Mossbauer spectrometry, magnetic susceptibility and microscopic infrared spectrometry.

During 1987, the Chemical Laboratory carried out 43,109 determinations of a wide variety of elements in approximately 13,400 samples. The style of operation of the Laboratory showed the onset of a change to greater cooperation and sometimes integration of effort between Sections in carrying out analytical support. For this reason, the reporting of the number of determinations performed by individual Sections within the Chemical Laboratory, as in the past, has been discontinued.

The Chemical Laboratory Information Management System (CLIMS) was put into operation in the last quarter of 1987 to facilitate analytical sample tracking and reporting. It was extended to facilitate chemicals-supplies dispensing and inventory in the MSL Chemical Stores. Even with the brief experience with CLIMS to date, its potential as a tool for the management of the Laboratory was quickly appreciated. Modifications to do so will be undertaken in 1988.

During this review period, considerable effort was put into the development of flameless atomic absorption techniques. Methods using graphite furnace volatilization or hydride generation were developed for antimony, arsenic, selenium and tellurium to increase the laboratory's ability to determine ever lower levels in ores, concentrates and related materials.

Analytical method development in liquid chromatography was continued. Dynamic ion-exchange chromatography was applied to the determination of rare earths in steels, zinc-aluminum alloys, super-magnetic alloys and ores. High-performance liquid chromatography techniques were applied to the determination of bromide, oxalate, nitrate and arsenic anions and also to the speciation of arsenic(III) and arsenic(V) in solution samples.

The modification and development of analytical methods using atomic absorption, inductively coupled plasma-atomic emission and X-ray fluorescence spectrometry were carried out for the determination of many elements in both solution and solid samples of hydrometallurgical, ferrous and non-ferrous alloys, and environmental materials. The effectiveness of micro-wave assisted sample decomposition was investigated but showed advantage over

standard acid or fusion decomposition procedures only for the hydride-forming elements at low levels in base metal concentrates.

A mineral age dating service by fission track counting was initiated in this review period. A microscope and polishing equipment were acquired and the methodology for sample preparation was developed. The Chemical Laboratory participated in a joint project with the U.S. Geological Survey to estimate the age of two candidate reference mineral samples. Cost recovery was carried out for the Saskatchewan Research Council and the University of Ottawa.

Participation in national and international committee work continued. Most effort was again directed to the International Organization for Standardization (ISO). Examples are REMCO, the Council Committee on Reference Materials; TC 102 for iron ore standards; and TC 183 for standard methods of chemical analysis of copper, lead and zinc ores and concentrates. Chemical Laboratory personnel also contributed to the preparation of a manual for the International Atomic Energy Agency on the analytical chemistry for the uranium exploration, mining and milling industry.

The Chemical Laboratory through the Canadian Certified Reference Materials Project (CCRMP) continued to provide the Canadian industry with compositional certified reference materials that are characteristic of Canadian mining and mineralogical sites. Revenue from the distribution of CCRMP products increased 12% to $146,000. In 1987, a copper concentrate and a uranium concentrate were certified for sale. A suite of four base metal tailings samples were prepared for use as reference materials on behalf of the Reactive Acid Tailings Program (RATS). CCRMP facilities continued to serve as a resource centre for reference material preparation for four projects by industry and other agencies. Of these, two for Newmont Exploration and one for the Aluminum Company of Canada were cost recovery projects.

The Chemical Laboratory participated in cost recovery work in the Extractive Metallurgy and Mineral Processing Laboratories. Analytical support was provided for projects such as the Royal Canadian Mint Sweeps, Madeleine Mines and Barrick Resources. Non-routine analytical support for outside agencies, for example, Communications Canada, Canberra Packard Canada Ltd., etc., was also performed on a cost recovery basis.

A commercial differential scanning calorimeter and associated software was commissioned. It enables examination of, for example, new advanced materials such as amorphous metallic alloys and ceramics. In particular, sample purity, thermal and physical properties, and conditions of sample preparation can be monitored sensitively.

EXTRACTIVE METALLURGY LABORATORY

The Extractive Metallurgy Laboratory provides a body of knowledge, expertise and experience over a wide range of technology for the mineral industry. Research work strengthens the knowledge base, develops new approaches to the resolution of process problems, and leads to enhanced industrial productivity.

The effectiveness of technological development is ultimately measured in terms of applicability in the Canadian industry. Indicative of this are a number of items:

(a) Recovery of elemental selenium from waste waters by biosorption.

(b) Separation of platinum group metals by solvent extraction.

(c) Alternative technology for iron control in zinc roast-leach-electrowinning.

(d) Characterization of impurity distribution in copper refining.

(e) The deportment of silver during zinc processing has facilitated the enhanced recovery of this precious metal.

(f) Infrared determination of quartz in mine dusts.

(g) Characterization of limestones for use in desulphurization in fluidized bed combustion of coal.

Research activities include the investigation of some if not more fundamental scientific phenomena. Developments in the behaviour of several sulphide and oxide materials as photocatalysts and in photoelectrochemical reactions may lead to enhanced oxidation rates in solution and to control of surface sensitive reactions. Thermochemical studies of arsenides and arsenates will enable better prediction of the behaviour of such systems in pyrometallurgical processes.

A comprehensive investigation of chloride metallurgy for sulphide mineral treatment has resulted in the development of a flowsheet which may be competitive with conventional pyrometallurgical approaches. This work has also led to developments in the use of surfactants in leaching, to unique solution purification strategies including iron control, and to new understanding of electrowinning chemistry.

Work on the behaviour of silver in zinc refining has aided industry in developing new processes to recover silver. The deportment of silver during processing and more sensitive silver analytical methods has facilitated improved recoveries of precious metals in zinc plants. The effect of some 15 impurities in conjunction with glue on zinc electrowinning has provided additional guidance to industry.

Cooperation with industry, universities and other researchers on improved technologies for control in copper electrorefining has gained support. Impurity control is a major concern in achieving the productivity levels necessary for Canadian plants to maintain competitiveness. Work on characterizing anode impurities and anode slimes composition has provided new insights into control mechanisms. Furthermore, cathode passivation is being related to impurity levels. Alternative treatment techniques for anode slimes have been completed.

One of the strengths of the Extractive Metallurgy Laboratory is technology for solution purification. Research targeted at improving uranium recovery systems is now being directed at gold, platinum group metals, rare earths and several minor metals. Advances have been made in solvent-in-pulp for gold recovery, in PGM separation, in applications to gallium, nickel and rare earths separation, and in problem solving in industry.

Biotechnology is finding application in the mineral industry. The success of uranium in-place leaching has encouraged work on zinc and copper in cooperation with Manitoba under the Mineral Development Agreement. Enhancement of the capacity and performance of biosorbents is indicating industrial potential for uranium, zinc, copper and toxic metals such as selenium. Biological destruction of organics which interfere with metallurgical processes is being considered for on-site trials. Applications of aerobic and anaerobic biological systems may hold the key to the treatment of a number of mine wastes. The operation of BIOMINET has provided a mechanism for a wide range of contacts in Canada and abroad.

Environmental considerations are paramount. The formation of the cooperative Reactive Acid Tailings Stabilization (RATS) group has enabled industry, provinces, and federal agencies including CANMET to develop a clear focus on the required research to achieve "walk-away" technology for tailings and waste rock. Laboratory trials are helping to evaluate various methods to cover and treat these wastes to reduce the environmental impact. An evaluation of metallurgical sludges has indicated the need to develop improved treatment technology.

Improved slag cleaning has become a mechanism for increased recovery in smelting. In-house and contract work in this area have helped to elucidate options for improved practice. Other work in pyrometallurgy has related to applications of plasma to reduce the reliance of fossil fuels. The work on characterization of limestones as desulphurizers in fluid bed combustion has led to an internationally accepted technique.

The laboratory serves a number of other organizations. Major contributions have been made to the Canadian Standards Council and the International Standards Organization. Furthermore, individuals have organized many conferences, seminars and meetings sponsored by a number of bodies such as the Canadian Institute of Mining and Metallurgy.

The Extractive Metallurgy Laboratory provides a number of diverse functions. These are but a few. Throughout this annual report, projects are described in more detail.

MINERAL PROCESSING LABORATORY

The Mineral Processing Laboratory carried out in-house investigations and contract studies in support of the needs of the Canadian minerals industry. The program is developed in close consultation with industry and with the province (through Mineral Development Agreements) and is carried out in cooperation with industrial R&D performers, private research companies, provincial research organizations and universities. Major projects are underway in the processing of metallic ore , coal, and industrial minerals, in the development and testing of improved construction materials, especially concretes, and in the preparation and treatment of ceramic products, both traditional and advanced. These activities are supported by a range of mineralogical investigations, particularly aimed at process design and optimization.

A new release of SPOC (Simulated Processing of Ores and Coal) was announced at the Computer Applications in the Mineral Industry Conference held in Quebec City in March 1988. While the new version contains the same basic algorithms, it features vast improvements in user oriented features. The new package, currently being sold, has graphic flowsheet design, automatic flowsheet analysis, full screen type-in-the-form data entry and many other features.

Four projects in expert systems were underway during the period, all cost-shared with industry and involving practical applications of the technology. A project involving control of a cement clinker grinding circuit and another addressing control of a zinc refining process were completed. Two other projects, related to tar sands extraction and Cu/Zn flotation are still underway. As a result of these projects, CANMET has had an opportunity to examine and compare many of the major hardware/software alternatives available for expert systems applications.

A fully instrumented flotation column has been installed (6.5 cm diam, 7 m length) which will form the flagship of a major activity on column flotation. The project will focus on joint work with industry and will feature CANMET expertise in mineralogy, process simulation, expert systems, flotation chemistry and instrumentation. The column will be integrated into the Continuous Process Development Unit and will take advantage of new instrumentation recently acquired (bubble size analyser, particle size analyser, zeta potential analyser).

The role of pyrite grain size and the morphology of associated base metal sulphide grains has been studied in detail, via electron-microscope-based image analysis, to predict liberation characteristics of mixed sulphide ores. The ability to differentiate between sulphide minerals present as discrete grains, as interstitial fragments or as intragranular particles is crucial for predicting the liberation of valuable minerals at a particular grind.

In joint work with Curragh Resources, a mineralogical assessment of the performance of the current mill was conducted through determination of optimum grinds and recoveries and a comprehensive flowsheet analysis, sam-

pling and mass balance of the circuit. Curragh is now using the SPOC package for routine mass balance calculations.

A number of studies on the mineralogy of platinum group metals in Canadian deposits including Bird River (Manitoba) and Wellgreen (Yukon) were completed.

In asbestos related projects, a prototype monitor capable of measuring airborne asbestos fibre concentrations as low as 0.5 fibres/cc has been developed and arrangements for commercialization are underway. A scaled-up pilot plant for wet processing of asbestos is under construction at Cassiar Asbestos, representing a further step in the development and transfer of this technology. Studies are also underway to develop improved ways of characterizing fibre, leading towards on line quality and/or process control.

Work is underway with a number of companies through secondment of staff to our laboratories and other technology transfer mechanisms, to commercialize a number of advanced ceramic materials. Following a joint program to produce improved lead titanate based piezoelectric ceramics, BM Hi Tech Inc. of Collingwood, Ontario has begun marketing an improved 50 MHz transducer for NDT applications.

Work on toughened ceramics remains a major component of effort. Alternate routes to preparing zirconia toughened alumina have been developed and a number of companies have expressed interest in these technologies. A process for preparing toughened mullite has been developed which yields a product with properties superior to any covered in the literature. Hydrothermal and organometallic processing routes to other toughened and wear resistant ceramics are under investigation.

Last year, MSL reported the development of a superplasticized concrete with more than half its cement replaced by fly ash. The resulting concrete showed superior strength and modulus and reduced permeability. This material has already been utilized in the foundation columns of a high-rise building in Halifax, exceeding specifications at reduced cost. Engineering data are still being collected on this generic material and various test blocks have been cast in Halifax and Toronto.

In this same field, MSL has sponsored a number of very successful and effective seminars and workshops - on silica fume in concrete (Montreal), slags in concrete (Toronto) and fly ash in concrete (Halifax). A major international conference on "Performance of Concrete in Marine Environment" is scheduled for August 1988 in St. Andrews, New Brunswick. In addition, CANMET published a comprehensive book entitled "Supplementary Cementing Materials".

MINERAL DEVELOPMENT AGREEMENTS

Beginning in 1984, under the "umbrella" of Economic and Regional Development Agreements, the federal government and the provinces negotiated a number of federal/provincial Mineral Development Agreements (MDA's). Currently, Agreements are in place with nine of the ten provinces and both territories. The objective of these agreements is to strengthen and diversify the mineral industry in a province to enable minerals to make a maximum contribution to the provincial economy.

The Mineral Sciences Laboratories of CANMET has major responsibilities for the Federal Processing Technology component of those MDA's which involve R&D. Thus MSL is involved directly in MDA's with Newfoundland, Nova Scotia, New Brunswick, Manitoba and Saskatchewan and plays an advisory role in Agreements with Quebec, British Columbia, Prince Edward Island, Yukon and Northwest Territories. The research work is carried out by contractors selected from industry or from private or provincial research organizations. MSL's role is, in consultation with the provinces, to prepare work programs, provide expert advice and guidance and act as Scientific Authorities on contracts. More than 53 separate contracts have been initiated to date. Total expenditures for 1987/88 are forecast at slightly more than $4 M.

During the 1987/88 period, the effort in the Newfoundland MDA was directed towards improved iron ore processing and the assessment of metallic and non-metallic deposits. In Nova Scotia, processing work was focussed on identifying and developing new sources of industrial minerals and construction materials while in New Brunswick, focus was on construction materials and developing extractive processes for sulphide minerals. In Manitoba, work was directed to non-ferrous smelter technology and industrial minerals and in Saskatchewan, to the dry processing of potash.

In subsequent sections of this document, MDA contracts are described as part of the Project under which they fall (e.g., the Newfoundland MDA contracts on iron ore are described under the MSL Project Iron Ore Processing). MDA contracts are designated as such by the letters MDA, written after the Contract Requisition Number.

SPECIAL AWARDS

Dr. J.E. Dutrizac and J.L. Jambor were awarded the Consolidated Gold Fields Silver Medal for 1987 by the Institution of Mining and Metallurgy, London, England for the paper entitled "Behaviour of Silver During Jarosite Precipitation".

Dr. Daniel Laguitton, received first prize from the Society for Technical Communication for his paper "L'intelligence artificielle appliquée au service de la minéralurgie" which was published in GEOS. The article was awarded the "distinguished" designation.

V.M. Malhotra was awarded the Distinguished Service Award of the Atlantic Chapter of the American Concrete Institute in February 1988. He was the first recipient of this award which is given in recognition of his work in concrete research and development.

Dr. W. Petruk was the first recipient of the Julian Boldy Award presented by the Geology Division of the CIM. The award is in recognition of the long-term contributions made to the Division, of which Dr. Petruk is a past-Chairman. Dr. Petruk has received further recognition in being appointed as a CIM Distinguished Lecturer for 1988/89.

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PART A. RESEARCH AND DEVELOPMENT

MINERAL AND ENERGY TECHNOLOGY ACTIVITY

MINING SUB-ACTIVITY

Rock Mechanics

- **Project 14.25.05: Underground Nuclear Waste Repository**
  Project leader : V.V. Mirkovich

Objective:

To characterize petrographically rocks occurring in sites being examined for possible disposal of nuclear wastes, and determine their thermophysical properties from representative specimens.

To simplify the laborious process of preparation of rock specimens for measurement of thermophysical properties, a different preparation method was devised. Rather than machine the cylindrical specimens, special, close-tolerance core drills were used to cut the specimens. The results were encouraging but, to attain the required precision, the simplified method requires further refinements. Preparation of East Bull Lake specimens continues; however, no thermophysical measurements could be made during this period.

Mine Environment

- **Project 14.39.01: Ventilation and Respirable Dust**
  Project leader : J. Bigu

Variation in the particle size of quartz can be determined by examination of the A_{800}/A_{min} ratio of the doublet in the infrared adsorption spectrum of quartz. Plots of the A_{800}/A_{min} ratio as a function of location on a quartz deposit were prepared for a number of samples deposited on filter membranes under different sampling conditions. There appeared to be no significant pattern of particle size variation across the deposits except for some deposits prepared in a laboratory-scale air chamber with a heavy dust cloud. Particle size appeared to decrease toward the perimeter in deposits where some leakage occurred around the perimeter of the filter.

The Digilab FTS-40 FTIR spectrometer was used to re-examine deposits previously examined by dispersive IR spectrometry. The calculated peak area of

the quartz doublet for standard quartz deposits prepared in the laboratory-scale dust chamber was on average 1.4 times that obtained using the dispersive instrument. Spectra in the 200-250 cm^{-1} range were obtained for mine dust deposits on filters after subtraction of the filter spectrum.

A report is being prepared.

COAL MINING AND PREPARATION SUB-ACTIVITY

Coal Desulphurization

- **Project 20.79.01: High Sulphur Coal**
  Project leader : K.S. Moon

Objective:

To contribute to the technology of economically upgrading high sulphur coals to meet more stringent specifications for thermal and metallurgical coals and future requirements for coal combustion, conversion and environmental considerations.

Atmospheric emission of SO_x from coal-fed thermal power plants is a major source of acid rain in the Atlantic region of North America. Coal from Eastern Canada contains significant amounts of sulphur and thus contributes to the problem. The efficient removal of sulphur and ash containing minerals from high-sulphur coals prior to combustion would reduce this problem. Removal of unwanted components also increases the unit thermal value of coals and contributes to decreased transportation costs. Coal preparation will generally be necessary for coals destined for other uses such as liquefaction or gasification.

Project Summary:

(a) Magnetic treatment of Canadian coals

The dry magnetic beneficiation of Kipp (Petro Canada), Lingan and Prince (DEVCO) coals using an open gradient High Intensity High Gradient (HIHG) magnetic separator has been completed. Results indicate that relatively high tonnages (up to 5 tons per hour per meter of magnetic roll) can be processed without impairing the ash-coal separation results. A final report on the subject matter is being prepared by Cryogenic Consultants. The performance of the open gradient HIHG magnetic separator will be compared with other types.

(b) Deep cleaning of high sulphur coals

The Donkin-Morien coal was characterized by dense liquid separation and mineralogical studies. It was cleaned intensively using progressive grinding followed by flotation and magnetic separation. Under the most favorable conditions, a coal product analyzing 1.1% ash and 0.16% pyritic, 1.20%

organic and 0.01% sulphatic sulphur was achieved with 84% thermal yield. A good correlation was obtained between the mineralogy and washability data throughout the flotation-magnetic separation tests.

(c) Dry processing of coal

Several Canadian coals were pre-concentrated using a novel rare-earth permanent magnetic roll. It was found that the method gave good coal-ash separation at particle sizes from 0.1 mm to 1.5 mm on coals which were sufficiently liberated. The technique was demonstrated at International Conferences in Edmonton and Lexington in collaboration with Eriez Magnetics using Lingan coals. Economic evaluation of the process is in progress.

(d) Pilot plant cleaning of high-sulphur Prince coal

The final report has been issued on a joint study which was carried out by CANMET and Electric Power Research Institute for the cleaning and combustion of Prince coal (500 tonnes) from Sydney, N.S. The raw coal (20.5% ash, 3.50% S) was cleaned using heavy medium cyclones (-19.05 + 0.60 mm) and water-only cyclones (-0.60 + 0.25 mm) with/without froth flotation (-0.25 mm). The results showed that the ash removal was successful while sulphur removal was relatively difficult due to fine dissemination of pyritic sulphur. However, up to 67% sulphur reduction was realized along with 93% reduction in ash content, resulting in an increased thermal content of the cleaned coal. An economic evaluation of the pilot-scale combustion tests of the raw and cleaned coals indicated that the increased level of cleaning led to lower estimated capital costs through reduced pulverizer requirements and potential use of smaller furnaces, flue gas desulphurization systems, and electrostatic precipitator systems for fly ash. Cleaning also reduced power requirements, scrubber additive consumption, and waste quantities, thereby producing operational savings that increased with deeper cleaning. Consequently utilities replacing the raw coal with the cleaned coal can save up to 44 $/kW in power plant capital costs and could afford to pay as much as 29% more for this cleaned coal without raising busbar costs.

(e) Development of "CANMET sulphur form analyzer"

A prototype CANMET Sulphur Form Analyzer is being developed by Barringer Research Limited under contract to CANMET for the quantitative analysis of different sulphur forms in coals, based on a patent-pending process developed in CANMET. In conjunction with LECO SC-32 total sulphur analyzer, an electronic microprocessing system was developed for the acquisition, processing and storage of spectrochronogram data. The system is capable of deconvoluting the multiple peaks of IR spectrochronograms of SOx compounds to give the contents of different sulphur forms. A new method of sample preparation was also the subject of a patent application in Canada and the U.S.A. Completion of the current project is scheduled for August '88. If a successful prototype is developed it will be tested in the field.

Contracts:

- Reqn. 4-9164, "Dry magnetic separation of the Eastern Canadian coal", Cryogenic Consultants Ltd., U.K. S.A. - G.I. Mathieu.

- Reqn. 5-9219, "Development of a prototype CANMET sulphur form analyzer", Barringer Research Limited. S.A. - K.S. Moon.

Reports/Publications:

- Mathieu, G.I. "Mineralogy and intensive cleaning of Donkin-Morien coal"; Division Report MSL 87-31 (OP); April 1987.

- Moon, K.S. and Sirois, L.L. "Theory and industrial application of column flotation in Canada"; Chapter II in Column Flotation 88, Proceedings of International Symposium on Column Flotation, ed. by K.V.S. Sastry; SME/AIME, New York; pp. 91-102; Phoenix, Arizona; January 1988.

- Moon, K.S. and Sirois, L.L. "The improvements in peak resolution and in reproducibility of spectrochronograms of different sulphur forms in coals by addition of silica (SiO_2) powder to coal sample"; Division Report MSL 87-117 (IR); August 1987.

- Moon, K.S. and Sirois, L.L. "Theory and application of column flotation"; CANMET Report 87-7E; December 1987.

- Moon, K.S. "Procedure for the deconvolution of the second peak for organic sulphur 2 (S_{O2}) and pyritic sulphur (S_{p2}) in infrared SO_x spectrochronogram of coals"; Division Report MSL 87-156 (IR); December 1987.

Patents:

- Moon, K.S. and Sirois, L.L. "Methods and apparatus for analyzing different sulphur forms"; Canada Patent Application No. 551,292; November 6, 1987.

- Moon, K.S. and Sirois, L.L. "Methods for analyzing different sulphur forms"; U.S. Patent CIP Application No. 119,915; November 13, 1987.

MINERAL PROCESSING SUB-ACTIVITY

Minerals Evaluation

- **Project 30.05.01: Mineralogical Evaluation of Ores**
  Project leader : P.R. Mainwaring

Objective:

To assist in the development and processing of Canadian mineral resources including various large tonnage, low grade and complex deposits of metallic

minerals and industrial mineral occurrences by assessment of the mineralogy, valuable element distribution, and probable liberation characteristics and by subsequent bench tests directed toward the improved recovery of the contained minerals.

(a) An investigation to determine the optimum grinds and recoveries by flotation of metals from a fine-grained lead-zinc ore from the Faro deposit, YK, was carried out in order to benchmark the current mill operation. Bench tests conducted at a primary grind of 63% -38 μm and a regrind of rougher concentrates yielded lead and zinc concentrates grading about 54% Pb and 53% Zn and recovered 83% of the lead and 75% of the zinc in the respective concentrates. Quantitative liberation studies by image analysis of the mill products showed that optimum grind had been achieved. The maximum recoveries that could be obtained are 87% of the zinc and 85% of the lead and at this grind, 4% of the zinc and 11% of the lead was in the 1 μm slimes fraction.

(b) As part of a long-term evaluation of ore characteristics and mineral-processing plant performance in British Columbia and the Yukon Territory, a joint project with Curragh Resources was undertaken to introduce SPOC methodology to the lead-zinc-silver mill at Faro. This involved flowsheet analysis, a sampling campaign of the mill, extensive sample processing and assaying, and the use of MATBAL software to achieve a metals balance of two lines of the grinding circuit and the entire flotation circuit. Curragh Resources is now using the methodology to calculate daily metals inventories in the mill. Future work, under a proposed cost sharing agreement, will use the techniques of quantitative image analysis to determine the distribution of minerals and metals in the plant using BILMAT software into which image analysis data can be incorporated.

(c) A quantitative study of chromite ore from the Bird River deposit, Manitoba was carried out in co-operation with the Province of Manitoba. The investigation determined liberation characteristics of chromite and gangue using image analysis techniques. A chromite liberation of only 70% at a grind of 100% -38 μm was predicted. Chromium-to-iron ratios in the chromite are low compared to those for conventional metallurgical usage.

(d) Mineralogical investigations have shown that the principal mineral of yttrium in the Strange Lake deposit, Quebec-Labrador, is a new Ca-Y silicate.

(e) A prototype asbestos fibre monitor, utilizing a solid state laser, has been designed for non-compliance applications and built under contract. The monitor is currently being assessed by the private sector for its commercialization potential, detectability limit and accuracy.

(f) The first phase of a study of the occurrence and nature of the platinum-group element distribution associated with chromite in the lower part of the Chromitiferous Zone in the Bird River Sill, S.E. Manitoba, has been completed [MSL Division Report 87-132 (R)]. Though being 5 μm or less in

diameter, 99 vol % of the PGM occur included in silicates or sulphides. This distribution has important implications for mineral beneficiation. Two samples from the Upper and Lower Main Chromitites, on the other hand, have a different PGM distribution with chromite the host for 43 vol % of the PGM and the balance occurring as inclusions largely in silicates.

(g) A study of one of five samples from the Cu-Ni-Pt-Pd bearing Wellgreen deposit, Yukon, has been completed as a cost-shared project. The other four samples are being prepared for mineralogical study.

Contracts:

- Reqn. 5-9209 and 5-9210 MDA, "Pt. Leamington deposit, Nfld, Phase 1 - sampling and Phase 2 - mineralogy and metallurgical testing", Noranda Research Centre. S.A. - J.L. Jambor.

- Reqn. 5-9217 MDA, "Evaluation of options for treating New Brunswick manganese minerals", Atlantic Analytical Services. S.A. - G.M. Ritcey.

- Reqn. 6-9056 MDA, "Quartzite evaluation, Wabush Lake, Labrador", Golder Associates. S.A. - R.K. Collings.

- Reqn. 6-9063, Development of an improved ambient air monitor for asbestos fibre", METREX Instruments, Ltd. S.A. - P. Mainwaring.

- Reqn. 7-9160, "Study on asbestos fibre counting stopping rules". S.A.- P. Mainwaring.

Reports:

- Cabri, L.J. and Laflamme, J.H.G. "Mineralogical study of the platinum-group element distribution and associated minerals from three stratigraphic layers, Bird River Sill, Manitoba"; Division Report MSL 87-132 (R).

- Jambor, J.L. "Geology and origin of the orebodies in the Lucky Strike area, Buchans, Newfoundland"; Geological Survey of Canada Paper 86-24, 75-106.

- Jambor, J.L. "Geology and mineralogy of the Tulks pyritic massive sulphide deposit"; Geol. Surv. Canada Paper 86-24, 219-226.

- Jambor, J.L. and Owens, D.R. "Vinciennite in the Maggie porphyry copper deposit, British Columbia"; Can. Mineral., v.25, 227-228.

- Jambor, J.L., Roberts, A.C. and Grice, J.D. "Armstrongite from the Strange Lake alkalic complex, on the Quebec-Labrador boundary, Canada"; Powder Diffraction, v.2, 2-4.

- Jambor, J.L., Carson, D.J., Stemerowicz, A. and Petruk, W. "Predictive metallurgy and bench flotation tests of massive sulphide ores from Tally Pond, Newfoundland"; Process Mineralogy VI, AIME, 255-272.

- Petruk, W. and Sikka, D.B. "The formation of oxidized copper minerals at the Malanjkhand porphyry copper deposit, India"; Process Mineralogy VII, AIME.

- Petruk, W. "The MP-SEM-IPS image analysis system"; CANMET Report 87-1E.

Beneficiation - Metallic

- **Project 30.13.01: Computer Aided Mineral Processing (CAMP)**
  Project leader : D. Laguitton

Objective:

To provide the technology transfer necessary to improve the recovery and/or value of minerals from the processing of Canadian ores through the application of modelling and simulation of minerals and energy processes, by providing the mineral industry with an easily usable computer methodology for circuit evaluation, control and optimization.

Project Report:

In 1987/88 activities remained focused on two parallel areas:

1. Conventional computer aids for mineral process evaluation and optimization.
2. Expert systems prototyping in mineral processing.

In 1987, significant progress was made in bringing the SPOC programs for material balance computation and process simulation to a first class level of user friendliness and functionality. The target was the announcement of a new release of software at the First Canadian Conference on Computer Applications in the Mineral Industry (CAMI) held in Quebec City in March 1988. The following packages were completed and displayed in their new format:

MATBAL5, a material balance program based on the well accepted MATBAL algorithm widely distributed in the previous phases of the SPOC project. The new version features graphic flowsheet definition, automatic flowsheet analysis and generation of mass balance equations, full screen type-in-the-form data entry, keyboard help facilities and faster execution time.

STAMP, a statistical package for data regressions and curve fitting offering a vast menu of state-of-the-art modules for linear and non-linear curve fitting as well as direct search techniques.

UNISIM, a collection of mineral processing unit simulators driven by a general menu. Feed description and parameter definition is done also in full colour screen formats, and program outputs can be plotted at execution time.

SIMBAL, a general flowsheet simulator offering a selection of three subplant simulators: **GRINDEX** for a grinding plant, **HCONEX** for multicyclone arrangements and **SPLITX** for general predictive material balance computation based on mixers and separators described by split coefficients. Data entry is graphic and full screen.

CRSHEX, a crushing plant simulator based on manufacturer models and performance data, also driven by graphics and full screen data entry. This program should be of exceptional value for equipment lay-out in small quarry operations.

SPOC.LIB, a library of FORTRAN callable programs for screen and window management in IBM-PC's and compatibles.

METCAL and **NPRD**, general utility programs for recovery calculations in laboratory experiments and for quick material balance by the n-product formula.

The new programs are available from CANMET/MSL under a new release formula. A few other packages will be added to the above list in early 1988-89.

The assessment of expert system technology initiated in 1986-1987 was successfully pursued in 1987-1988. CANMET hosted a Symposium on Expert Systems in the Mineral Industry on March 31, 1987 that brought together technology suppliers and users and ensured continued contacts with industry during the entire fiscal year. The technology approach was pursued, in which CANMET sought to assess as many different routes as possible in expert system prototyping. A special assessment was done through contracts for the following development tools:

- **KEE/TI-EXPLORER**, in a cement grinding domain, with Canada Cement Lafarge;
- **Personal Consultant/Compaq 386**, in a zinc refinery domain, with Fenco-Lavalin and Noranda-CEZ;
- **PICON/LAMBDA**, in a general in-house training project.

Furthermore, two projects were defined and brought to start-up status for expert system prototyping with real-time components, in a tar-sand extraction pilot plant and in a copper and zinc flotation plant.

Contracts:

- Reqn. 6-9137, "Pilot application of expert system technology to process control", Cosigma Lavalin Inc. S.A. - D. Laguitton.

- Reqn. 7-9047, "Development of a model for the analysis of a potash compaction circuit", Kilborn (Saskatchewan) Ltd. S.A. - D. Laguitton.

- Reqn. 7-9214, "Development of an expert system for process control in a flotation plant", Falconbridge Ltd. Kidd Creek Mines Div. S.A.- D. Laguitton.

Reports:

- Laguitton, D. (ed.) "Proceedings of the CANMET Symposium on expert systems in the Mineral Industry, Ottawa"; CANMET SP 87-4E; March 1988.

- Laguitton, D. and Barcados, A. "L'intelligence artificielle appliquée au Service de la minéralurgie"; Geos 16:3-1; 1987.

- Laguitton, D. "Expert systems in mineral processing"; Proceedings of the 20th Conference of the Canadian Mineral Processors Division of the CIM; Ottawa; January 1988.

- Laguitton, D. and Bilodeau, M. "Computer aided mineral processing simulation and expert systems"; Proceedings of the Copper87 Conference; Vina del Mar, Chile; Vol. 2; December 1987.

- Laguitton, D. and Pilgrim, R. "Computer aided mineral processing: The role and contribution of CANMET"; Proceedings of the First Canadian Conference on Computer Applications in the Mineral Industry; Quebec City; p. 127; March 1988.

- Flament, F., Vanderstichelen, J., Laguitton, D. and Hodouin, D. "Prototyping an expert system for the trouble-shooting of a clinker grinding mill"; Proceedings of the Conference on Artificial Intelligence in Minerals and Materials Technology; University of Alabama; Tuscaloosa; October 21, 1987.

- Flament, F., Vanderstichelen, J., Laguitton, D. and Hodouin, D. "Tool assessment in expert system prototyping: The KEE expert system shell"; Proceedings of the First Canadian Conference on Computer Applications in the Mineral Industry; Quebec City; p. 565; March 1988.

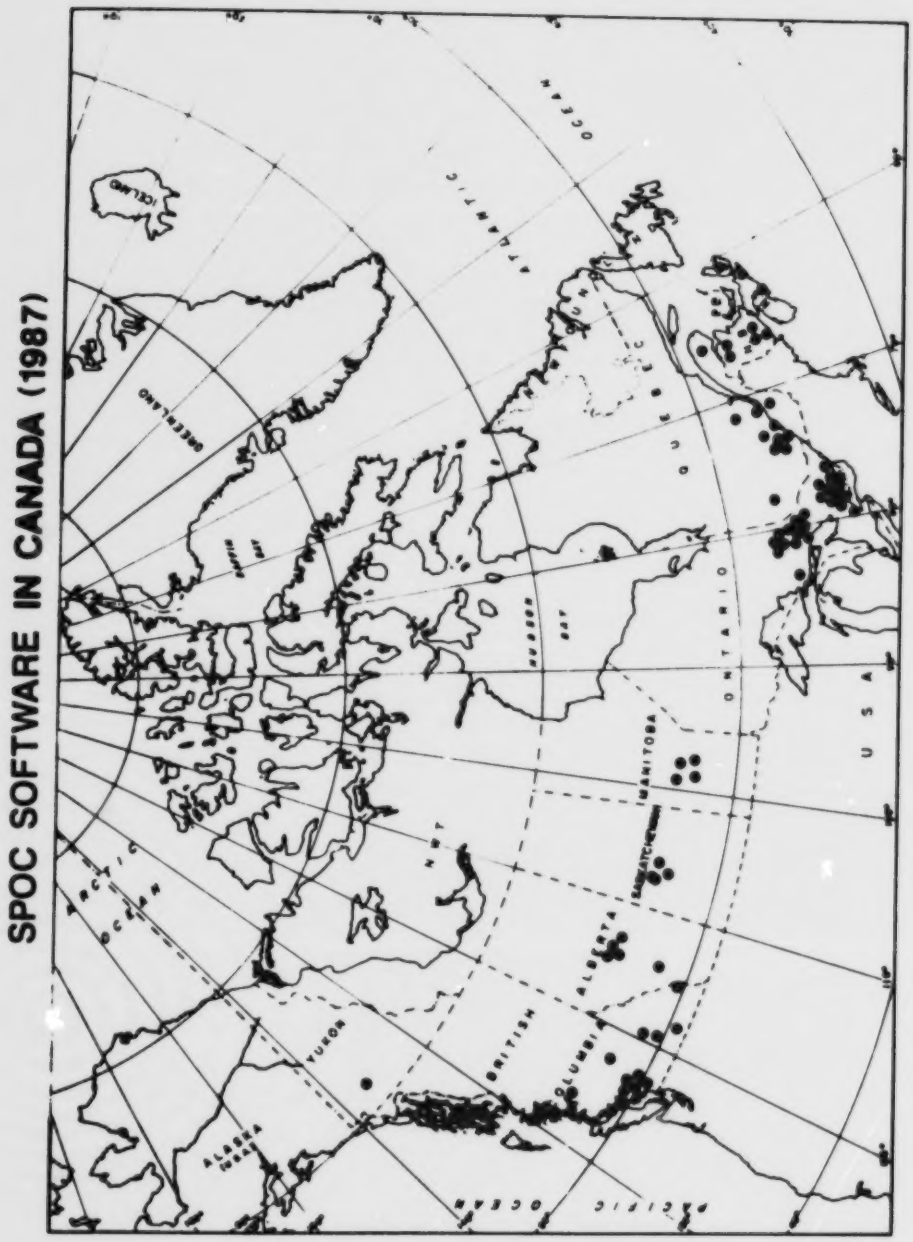

Fig. 1. SPOC software use in Canada

• **Project 30.13.02: Iron Ore Processing**
Project leader : W.H. Cameron

Objective:

To maintain the viability and competitiveness of the Canadian iron ore industry by identifying and investigating methods to increase recovery, improve grade and quality of ore concentrates and pellets, reduce energy costs, improve process control and lessen environmental impact.

It has become increasingly apparent in an iron ore buyer's market that Canada cannot assume it can compete in any market. High labour and energy costs have made pellets less attractive than sinter feed for a blast furnace. The Canadian iron ore industry finds itself in a position which is less competitive than formerly. There is a need to improve efficiency, reduce energy costs and improve product quality and recovery.

(a) Alternative binders for pelletizing

Pelletizing of iron ores concentrates from Mount Wright and Carol Lake with partial and full substitution of bentonite by several organic binders was investigated. Carboxy methyl celluloses, hydroxy ethyl cellulose and modified guar gum all produce pellets of acceptable wet, green and dry strength. However, when fully substituted, an inorganic binder such as calcium carbonate is required for satisfactory strength development after induration.

(b) Cold bonded pellets

Acceptable crush-strength has been obtained for pellets produced by the cold-bonding technique. In this process, iron ore concentrate fines, sinter-feed and calcium hydroxide are blended together in a mixer and pellets are produced by balling with water. After partial drying in an oven at 100 °C, to about 6% moisture, they were hardened with CO_2. A mixture containing 40 wt % sinter-feed, 60 wt % concentrate fines and 8 wt % calcium hydroxide produces the strongest pellets after 72 h carbonation time.

(c) Flotation of Wabush spiral tailings

Iron concentrates using reverse amine flotation were made with Fe recoveries as high as 96%. Unfortunately 97% of the manganese also reported to the Fe concentrate. High intensity magnetic separation was tried to reduce the Mn in the concentrate. Although a definite improvement was observed, the Mn was still at an unacceptably high level. Further testing showed that 87% of the Mn was in the -325 M fraction. The best results obtained gave an Fe concentrate of 64.10% Fe, 1.23% Mn and 0.69% SiO_2 at recoveries of 77%, 19% and 36%, respectively.

(d) Quebec Cartier Mining spiral circuit

The behaviour of minerals in the Mount Wright Spiral circuit was investigated by sampling and studying the feeds, concentrates and tailings from rougher, cleaner and recleaner spirals in one mill line. Sized fractions of each

sample were analyzed with the MP-SEM-IPS image analysis system. Mineral quantities, liberations, characteristics and mass balance techniques were used to calculate a metal recovery for each stream and mineral recovery for each size fraction. The effect of finer grinding in mineral recovery was thereby evaluated.

(e) Mill recovery predictions from blast hole cuttings

These predictions are presently being made in the industry by separating ore from gangue by either wet tabling or heavy liquid separation with the products being assayed for elements of interest. Both of these methods are slow and tedious and are not capable of handling large enough samples of cuttings to be representative. To date, after investigating several different methods and equipment, no alternative methodology has been successful in surpassing present practice.

(f) Self dewatering concentrates

Work is ongoing regarding this problem with peat moss being tried as a water sequestering agent.

(g) Circuitry instrumentation

Over 80 brochures have been collected from various instrument manufacturers in an attempt to determine what kind of "off the shelf" instrumentation is available. At present a sub-committee of the 'Iron Ore Technical Task Force Committee' is being formed to discuss instrumentation required by the industry and possible sites where it could be installed for evaluation on a lend/lease basis.

(h) Other activities

Two meetings of the Iron Ore Technical Task Force Committee were held in Wabush, Labrador, on September 22, 1987 and in Ottawa on January 22, 1988 to discuss problems common to the industry.

Contracts:

- Reqn. 5-9196 MDA, "Increase of iron ore recovery". S.A. - M. Stefanski.

- Reqn. 6-9145 MDA, "To improve iron ore recovery at the Scully Mine, Labrador, Phase II and III". S.A. - M. Stefanski.

- Reqn. 6-9171 MDA, "Evaluation of the Bass River Nova Scotia magnetite deposit Lodestone Limited". S.A. - W.H. Cameron.

- Reqn. 6-9187 MDA, "Iron ore binders, Part 2". S.A. - J.M.D. Wilson.

Outside Contract Activities:

- Industrial Research Assistance Program of the National Research Council-Arrangement No. CA 103-7-1202, "Improved iron recovery" at Iron Ore Company of Canada. S.A. - W.H. Cameron.

- Natural Sciences and Engineering Research Council - Project No. CRD-8709, "Optimizing sinter quality and productivity using specular hematite concentrates in Canadian sinter mines". Liaison Officer - W.H. Cameron.

Reports:

- Kuriakose, A.K. and Quon, D.H.H. "Pelletizing of iron ore by partial or full substitution of bentonite by organic binders"; Division Report MSL 87-102 (TR).

- Quon, D.H.H. and Kuriakose, A.K. "Iron ore pellets requiring no induration"; Division Report MSL 87-150 (IR).

• **Project 30.13.03: Evaluation of New Processing Equipment and Techniques**
Project leader : D.G. Feasby

Objective:

To design, acquire and demonstrate scientific testing and mineral concentrating equipment not presently available in Canada.

(a) Mineral Processing

Column flotation was selected as the major priority area for acquisition of equipment and development of expertise. An automated system based on USBM design was purchased and installed in our laboratory. Commissioning tests will start in 1988/89.

Planned acquisition of a tower mill grinding unit, magnetic fluid separator and electroflotation systems were delayed or cancelled.

Two instruments for measuring fine particle size were acquired; a Brinkman particle size analyzer, and a Malvern zeta sizer. Both instruments use laser technology for size measurement and are equipped with micro computers for data analyses. The Brinkman can measure sizes from 150 to 1.5 μ and the Malvern 5 μ to colloidal. The Malvern can also measure zeta potential in liquid of choice.

(b) Mineralogy

(i) Automated powder diffractometer

The Rigaku Automated Powder Diffractometer (APD) is now fully functional as far as qualitative analysis and identification are concerned. The software

for quantitative analysis of up to five phases (to be supplied by the manufacturer) is still not complete, and there are still some aspects of software analysis which do not function. However, the instrument is proving its worth when precise measurement of powder diffractograms and identification are called for, and it is in such demand that a second Terminal, a Tektronix 4207 has been added this year. It is hoped soon to have this APD fully functional for qualitative and quantitative analysis.

(ii) Proton microprobe

Collaboration with the Department of Physics, University of Guelph, in the design and commissioning of a mineralogical proton microprobe has been successful to the point that a focussed 5 x 5 μm beam with a current of 2 Amp has been produced on a mineral target. Testwork is currently in progress on CANMET-produced synthetic standards to determine analytical parameters. A site visit in January, together with GSC personnel, has led to plans for inclusion of Canada's first mineralogical proton microprobe in several projects during 1988/89.

(iii) Thermophysical properties of solids: thermal diffusivity measuring system

Contact and radiation pulse generating heaters were designed and constructed for measurement of thermal diffusivity of 1-in. diam specimens. The pulse heaters proved to be quite effective; they have dramatically reduced (from half-a-day to just a few minutes) the time required for assembling the specimen column. The new pulse heaters also virtually eliminated electrical and electromagnetic interferences.

Publications:

- Mirkovich, V.V., Gaal, P.S. and Kareis, J.H. "A computerized thermal diffusivity apparatus"; Division Report MSL 87-133 (OP&J) Draft.

- **Project 30.13.04: Improved Recovery Technology of Fine Particle and Tin**
  Project leader : M.A. Cristovici

Objective:

To investigate methods to improve the recovery of fine mineral particles and to develop methods to improve the recovery of tin from base metal suphide flotation tailings.

(a) Selective flocculation of tantalum ore

Investigation carried out on single mineral species separated from a tantalum ore indicated that a stable suspension could be achieved at pH values higher than 10.

The stability of the mineral suspension was studied under fine grinding conditions and using various additions of several dispersants. The best results, 90% suspension stability, were obtained at 96% -20 μm grind, 5% solids in the slurry, pH = 11 and using 200 g/t Na-Meta-silicate as dispersant.

The stable suspension was then conditioned with various flocculants to obtain the selective concentration of tantalum species. The selective flocculation experiments were carried out in separatory funnels equipped with variable speed mixers. A large variety of flocculants of different chemical composition was tried. However, none of the flocculants showed any significant trend of selective concentration for tantalum. The ratio of concentration for tantalum in the flocculated product did not exceed 1.71 at a Ta recovery of only 19%. The highest tantalum recovery reached 71% but in this case the ratio of concentration was only 1.29 since more than half of the ore reported in the flocculated product.

It appeared that an efficient separation by flocculation could not be achieved in this case due to the low content of valuable minerals and to the complexity of the ore mineralization.

(b) Tin flotation using new developed reagents

Tin flotation is difficult and rarely applied around the world. Recently, Briquest reagents, a group of newly developed chemicals, has shown some promising results for tin flotation. Briquest is the trade mark of a family of organophosphonates marketed by Albright and Wilson for uses such as scale and corrosion control, ore flotation, dispersing and stabilizing solutions.

An investigation was initiated to select the most suitable collectors for tin flotation from the commercially available Briquest reagents. An ore sample containing 0.2% Sn was used for this work. Mineralogical study performed on ground ore indicated that a good tin liberation should be expected under -38 μm grind.

A Nagahm flotation machine was used to select the best collectors. This machine has a rotor of a special configuration that produces an intense agitation and large amounts of fine air bubbles well dispersed in the slurry. A supply of this kind of air bubbles is essential for the flotation of fine particles.

The Briquest reagent, 2N 81 - 25 S was found to be the most effective collector for this application. This reagent is a water soluble phosphonate with a hydrocarbon chain free at one end. It is adsorbed at solid/water interfaces and it is assumed that the aminobismethylenephosphonate group renders the adsorption selective for tin minerals.

Under -38 μm grind, at pH = 5 a tin concentrate of 0.62% Sn was obtained at a Sn recovery of approximately 78%.

Further testing is required to upgrade the tin concentrate.

If successful, the findings of this investigation would be used to upgrade other mineral sources of low tin content.

(c) Design of new electroflotation cell

A tank-electrode of special configuration was designed. It was decided that a 2-litre tank with a tapered top and a 45° "V" bottom with a 4 in. diam electrode on each side of the "V" would be suitable. This would give an electrode area of 81.1 cm^2/L which is 5.12 times greater than the first 4-L prototype. Also by tapering the tank towards the top it is possible to maintain a reasonable froth surface area/volume ratio of 39.5 cm^2/L for the 4-litre prototype. However, there are many difficulties in design to be overcome before a viable and safe machine can be produced for 100°C operation. The project was put in abeyance because of other priorities.

Contracts:

- Reqn. 6-9062, "Characterization and application of new organic depressants for the selective flotation of sulphide ores", Lakefield Research. S.A.-A.I. Stemerowicz.

Reports:

- Cristovici, M.A. and McCarthy, D.R. "Investigation to remove the sulphides from Kidd Creek mill tailing prior to cassiterite flotation"; Division Report MSL 87-71 (IR).

- **Project 30.13.05: Liberation/Flotation Models**
  Project leader : W. Petruk

Objective:

To develop a liberation model which predicts the mineral liberation that would be obtained at different grinds for different ore types, and to incorporate the predictive model into grinding and flotation models which have been developed at CANMET by the SPOC Program. Several liberation models, based on size distributions of minerals in unbroken ores, have been proposed, but in many instances the predicted liberation does not correspond to observed liberation. It is therefore necessary to determine the fundamental properties that affect liberation before a model can be developed.

It was found during the early stages of the investigation that by using the Finch and Petruk (1984) liberation model there was a close correlation between the observed and predicted liberation for sphalerite from base metal ores (Petruk, 1987) but not for chalcopyrite and galena. Subsequent work has indicated that the reason for the above observation is that the sphalerite in the ore tested occurs largely as separate grains, hence its liberation can be predicted from grain size distribution of sphalerite in the unbroken ore. By contrast, the chalcopyrite and galena occur largely in interstices in pyrite; therefore, their liberation may be controlled by the breakage of pyrite.

A study was conducted on the base metal ore from the Brunswick No. 12 deposit by (1) determining the size distributions of pyrite, sphalerite, galena and chalcopyrite in an unbroken base metal ore; (2) grinding the ore for different lengths of time; and (3) determining liberation characteristics and size distributions of the particles in the ground products. It was found that the mode of breakage is strongly influenced by the behaviour of pyrite. Similar size distributions were obtained for material from the 15-min grind in a laboratory ball mill, for the grinding circuit discharge from a commercial mill, and for pyrite grains in the unbroken ore. This similarity indicates that a 15-min grind breaks poorly bonded pyrite grains along grain boundaries, and represents the limit of easy breakage for the ore. Such a grind liberates both large separate grains of ore minerals and poorly bonded mineral grains that occur in interstices among pyrite. On the other hand, the 15-min grind neither separates moderately bonded mineral grains nor releases moderately bonded interstitial minerals from pyrite; a 45-min grind in a laboratory ball mill is required. It is assumed that, for Brunswick No. 12 ore, a 45-min grind in a laboratory ball mill is equivalent to regrinding in a commercial mill. Grinding beyond 45 min in a laboratory ball mill breaks the ore by fracturing pyrite across grain boundaries and by chipping grain edges. Such intense grinding does not markedly increase sphalerite liberation from Brunswick No. 12 ore because most of the sphalerite that can be released is liberated at the 45-min grind. In contrast, the intense grinding increases galena liberation because a significant proportion of the galena occurs as minute inclusions in pyrite. These findings show that ore breakage and coincident liberation depend upon size distributions, intergrowths and mode of occurrence of the minerals in an ore.

Contracts:

- Reqn. 4-9232 MDA, "Mineralogical studies of potash deposits", New Brunswick Research and Productivity Council. S.A. - W. Petruk.

- Reqn. 4-9235 MDA, "To determine mineralogical characteristics that affect the behaviour of copper, zinc, lead, silver and gold in copper, zinc and lead concentrates from Cu/Zn/Pb ores in Manitoba, Phase (1a) mineralogical characteristics of Trout Lake ore, Phase (1b) behaviour of Trout Lake ore during beneficiation", Hudson Bay Mining and Smelting Co. S.A.-W. Petruk.

Publications:

- Finch, J.A. and Petruk, W. "Testing a solution to King liberation model"; Int. J. Mineral Processing 12:305-311; 1984.

- Petruk, W. "Predicting mineral liberations in ores and mill products and effect of mineral textures and grinding methods on mineral liberation"; Process Mineralogy VI, AIME, New York; 1987.

- Petruk, W. and Smith, M.M. "Ore characteristics that affect breakage during grinding"; submitted to CIM Bull.

- Petruk, W. "Ore characteristics that affect breakage and mineral liberations during grinding"; Proceedings 20th Annual Meeting, Canadian Mineral Processors; CIM; 1988.

- **Project 30.13.06: Beneficiation of Complex Ores**
  Project leader : A.I. Stemerowicz

Objective:

To develop concentration methods for various types of complex metallic and precious metal ores which are not being exploited either because of a very fine-grained intergrowth between the minerals or because of a unique assemblage of less common minerals for which concentration technology has not been developed.

(a) Concentration of Kidd Creek copper-lead-zinc silver ore

Because of illness and other priorities (cost recovery) a start on this project was postponed till February 1988.

Beneficiation - Industrial Minerals

- **Project 30.21.01: Energy Conservation in Industrial Mineral Processing**
  Project leader : F.R. Campbell

Objective:

To develop technologies to reduce the energy content per unit of production in the industrial mineral sector.

The industrial minerals sector spends more money on energy as a production input than any other industry. In certain industries, such as cement, lime and gypsum, energy costs represent about one half of production costs. While the situation has improved somewhat since the days of cheap oil, further improvements require improved equipment design, process modification, fuel switching, use of less energy intensive materials as supplements and the optimization of energy flows. All of these require R&D to optimize processing conditions.

This project includes work in three main areas: (a) comminution; (b) firing of clay products; and (c) use of supplementary cementitious materials in concrete.

This program is supported largely through the federal energy R&D program under the Panel on Energy R&D. Most of the work is being carried out under contract.

(a) Comminution

Reducing the size of the as-mined materials to meet processing or end use requirements represents the major component of energy input in the processing of many industrial minerals.

Earlier phases of this project developed a database on current comminution methods for 10 common industrial minerals, and established a monitoring methodology for control of comminution circuits. Phase III got underway during 1985/86 and will develop, on the basis of pilot-plant tests, a detailed statement of technical requirements for implementing state-of-the-art comminution technology in the Canadian minerals processing industry. This phase will be completed in 1988 and will be followed by a demonstration of the most significant new technologies.

Phase III includes the following elements:

i) evaluation of high-efficiency classifiers;
ii) evaluation of classifier use in cement industry;
iii) use of grinding aids;
iv) use of on-stream particle size analysers;
v) wet comminution of asbestos;
vi) autogenous grinding of quartzite; and
vii) pilot plant testing of on-stream particle size control in a cement clinker grinding circuit.

Of these, five were completed before the reporting period began. The evaluation of classifier use in the cement industry was completed during the period; a report on this element was provided and a seminar presented to CANMET staff and cement industry representatives. The final element (pilot plant testing of on-stream particle size control) began during the period and will be completed during 1988. A final report will then be prepared and a summary of results will be presented in a number of public fora.

The results indicate that high-efficiency classifiers, on-stream particle size analysis and grinding aids could reduce comminution energy costs substantially and increase throughput in many industrial mineral plants. During the reporting period, discussions were held to develop a demonstration project (Phase IV) which would combine these features in a new cement clinker grinding circuit. The project would likely be cost-shared between the host company, EMR and a provincial government.

(b) Firing of clay products

The firing of clay products is a high temperature industrial process which utilizes large amounts of energy. Improvements which increase thermal efficiency, reduce the firing temperature or shorten the time can result in substantial energy savings.

The use of scrubbers to control fluoride emissions from brick kilns reduces the thermal efficiency of the kiln process. A CANMET sponsored study identified different firing schedules and/or additives as possible alternatives. However, when tested, neither approach showed itself to be generally effective. Canada Brick and CANMET are jointly pursuing studies aimed at identifying the release mechanism more precisely prior to defining a more rigorous attack on the problem.

In another CANMET sponsored study, new refractory blends were identified which would allow much lower firing temperatures in the manufacture of molds for metal alloy casting. An agreement has been reached with an alloy casting manufacturer to complete the development of this technology to the point of full scale commercialization under a joint funding arrangement. The project will begin in 1988.

(c) Supplementary cementing materials

The results of this component of the project are reported under the closely related project 30.37.01 - Performance and durability of concrete incorporating supplementary cementing materials.

Contracts:

- Reqn. 4-9263, "Energy conservation in comminution of industrial minerals Phase III: Development of pilot plant systems", Canada Cement Lafarge Limited. S.A. - T. Cienski.

- **Project 30.21.02: Beneficiation/Grinding Studies of Selected Industrial Minerals**
  Project leader : R.K. Collings

Objective:

To develop and improve processing methods for the recovery of minerals and mineral products, acceptable to specific markets, from selected industrial mineral deposits, and including improved methods for the production and classification of ultra-fine mineral material for specific applications, notably the filler/extender market.

Increased interest in recovery and use of industrial minerals had led to the development of a project that stresses processing technology development, particularly fine grinding and classification. The Industrial Minerals Laboratory was re-equipped and testwork was conducted on a variety of industrial minerals. Summary reports of past and current beneficiation studies at CANMET on the important industrial minerals are being done.

(i) Silica

A summary of an in-house study of silica resources of Canada, undertaken co-operatively with the various provincial governments was completed and prepared. A study of the reduction of Potsdam sandstone to its natural grain size in a Union Process, Szeqvari attritor, was completed. This study demonstrated the technical feasibility of using this unit as a one-stage secondary or tertiary crusher to reduce Potsdam sandstone to its inherent grain size.

Publication of the Summary Report on silica, "Silica in Canada", is scheduled for May 1988.

(ii) Barite, celestite and fluorite

A summary report on each of the three minerals is nearing completion. A small gravity concentration study was done of a sample of barite from near Thunder Bay.

(iii) Kaolin

Follow-up beneficiation work was done on drill core from the Black Island Manitoba kaolin - silica deposit.

(iv) Potash

Work continued on the beneficiation of potash by dry methods - magnetic and electrostatic. High gradient (2 tesla) magnetic separation may remove paramagnetic insolubles but full scale economics are yet to be proven. Titanium tetrachloride is one salt that shows potential for improving separation of chloride salts by electrostatics.

(v) Graphite

Beneficiation tests were started on several deposits and a summary report is to be prepared.

(vi) Mica

A major beneficiation program on a muscovite was conducted under cost recovery.

(vii) Asbestos

Asbestos R&D activities during FY 1987/88 were concentrated in four areas: (1) fibre concentration measurements; (2) wet milling; (3) fibre characterizations; and (4) asbestos cement product evaluation. This work was contracted out to (1) Metrex Ltd. who have developed a portable airborne monitor capable of measuring concentrations as low as 0.5 fibres/cc; (2) Cassiar Asbestos, who with CANMET and NRC support have operated a 1 TPH wet milling circuit recovering Group 4 fibre from tailing; (3) University of Sherbrooke who have characterized wet and dry milled fibres by microscopic and standard QAMA methods and have furthered the development of a rapid wet

fibre length measurement device; (4) CERAM/SNA of Sherbrooke who have produced superior quality asbestos cement pipe and sheet products from wet milled as compared to dry milled Group 4 Asbestos fibres.

CANMET has agreed to serve on the recently formed Asbestos Institute Research and Development Committee, and is participating in the identification and initiation of projects directed towards new product development, environment & health and process improvements.

(viii) Building stone

Interest in both architectural building stone and agglomerated stone continues to increase in Canada. A large number of inquiries from producers, potential producers, consultants and government officials concerning Canadian resources and production technology were received. Some ASTM tests were done on various stone products for various clients.

(ix) Chromite

In conjunction with the recommendations of the Manitoba Mineral Development Agreement, pilot scale flotation/gravity concentration of the Bird River chromite deposit is being done. The produced concentrate will also be used as an analytical standard and will be test reduced in the plasma furnace. CANMET personnel are actively involved in a study for chromium steel production.

(x) Other minerals

Beneficiation studies were undertaken on samples of wollastonite from two deposits, and on garnet, sillimanite, staurolite and feldspar. A pilot scale fine-grind beneficiation study was also completed on a Quebec talc ore.

(xi) Fine grinding/sizing

A contract was let to Ontario Research Foundation to determine, for four minerals, the technical feasibility of chemically modifying the mineral surface during grinding. In-house work was not as extensive as planned, limited to a sizing study with the Raymond classifier and fine grinding of anhydrite in support of a Nova Scotia MDA project.

Contracts:

- Reqn. 6-9163 MDA, "Preparation and evaluation of certain N.S. industrial minerals for use in fillers, extenders and chemicals", Magstone Development Inc. S.A. - R.K. Collings.

- Reqn. 7-9005 MDA, "Study of the production of barium chemicals from the Lake Ainslie Barite deposit". S.A. - D.G. Feasby.

- Reqn. 7-9049 MDA, "Evaluation of the production of potassium phosphate fertilizer in Eastern Canada". S.A. - D.G. Feasby.

- Reqn. 7-9035 MDA, "Investigation of the use of anhydrite - Phase I". S.A. - D.G. Feasby.

- Reqn. 4-9232 MDA, "Mineralogical studies of potash deposits". S.A.- W. Petruk.

- Reqn. 6-9147 MDA, "Prefeasibility study on the economics of the Bird River chromite deposits". S.A. - P. Andrews.

- Reqn. 7-9149 MDA, "Market evaluation for production of stainless steel and chromium chemicals". S.A. - P. Andrews.

- Reqn. 7-9189 MDA, "Heavy media separation of potash - Phase II". S.A.- D.G. Feasby.

- Reqn. 7-9226 MDA, "Dry magnetic separation of potash ore - Phase II". S.A. - D.G. Feasby.

- Reqn. 6-9122 MDA, "Offshore product quality". S.A. - D.G. Feasby.

- Reqn. 7-9221, "Offshore product quality - Phase II". S.A. - D.G. Feasby.

- Reqn. 7-9220, "Long term management of potash tailings". S.A.- D.G. Feasby.

Reports:

- Collings, R.K., Lavallée, M. and Szabo, E.I. "Sandstone reduction by attritor grinder: Product evaluation as foundry sand"; Division Report MSL 87-138 (IR).

- Andrews, P.R.A. and Collings, R.K. "Canadian silica resources: Processing studies at CANMET"; Division Report MSL 87-86 (J) Draft.

- Collings, R.K. and Andrews, P.R.A. "Summary Report No. 1: Barite in Canada"; Division Report MSL 87-107 (R).

- Collings, R.K. and Andrews, P.R.A. "Summary Report No. 2: Celestite in Canada"; Division Report MSL 88-1 (R).

- Collings, R.K. and Andrews, P.R.A. "Summary Report No. 3: Fluorite in Canada"; Division Report MSL 88-15 (R).

- Andrews, P.R.A. and Jackman, I. "Laboratory and pilot-plant beneficiation of chromite ore from Bird River, Manitoba"; Division Report MSL 87-8 (OP&J) Draft.

- Andrews, P.R.A. "Beneficiation of two samples of zeolite"; Division Report MSL 87-20 (IR).

- Andrews, P.R.A., Pearse, G.H.K. and Burt, R.O. "Product and market evaluation of a rubidium feldspar from Bernic Lake, Manitoba"; Division Report MSL 87-55 (OP&J).

- Andrews, P.R.A., Lamothe, J.M. and Joe, R.D. "Instructions for the use of a sedigraph 5000 ET particle size analyzer, with an Apple IIe computer"; Division Report MSL 87-61 (TR).

- Andrews, P.R.A. and Kelly, W. "Preliminary assessment of wollastonite from Marble Mountain area, Nova Scotia"; Division Report MSL 87-63 (IR).

- Andrews, P.R.A. and Morin, L. "Further flotation beneficiation studies on a sample of kaolin from Black Island, Manitoba"; Division Report MSL 87-74 (IR).

- Andrews, P.R.A. and Rouleau, J.P. "Laboratory and pilot-plant beneficiation of talc ore from Bakertalc, Highwater, Quebec"; Division Report 87-120 (IR).

- Andrews, P.R.A. "Separation of garnet and sillimanite from an anthophyllite gneiss, from the Star Lake - Elken Lake area, Manitoba"; Division Report MSL 87-121 (IR).

- Andrews, P.R.A. "Beneficiation of two drill core samples of kaolinised sand from Black Island, Manitoba"; Division Report MSL 87-142 (IR).

- Andrews, P.R.A. and O'Shaughnessy, D.P. "Economic assessment of the Bird River chromite deposits"; Division Report MSL 87-143 (OP&J) Draft.

- Andrews, P.R.A. and Kelly, W. "Beneficiation of a sample of staurolite from Barrie Township, South-eastern Ontario"; Division Report MSL 87-154 (IR).

Treatment - Ceramics

- **Project 30.29.01: Preparation and Characterization of Advanced Ceramic Materials**

  Project leader : T.A. Wheat

Objective:

To develop the technology for the fabrication and exploitation of various advanced ceramics for both structural and functional applications and to demonstrate their promising applications through technology transfer.

This project reflects the growing commercial interest in the use of ceramic materials for both functional (e.g., electrical, magnetic, optical, etc.) and structural applications. Some of the functional uses are in sensors of various kinds, NDT transducers, high energy-density batteries for electric vehicles, ion pumps and fuel cells. Structural applications are based on

toughened, wear-resistant, corrosion resistant and high-temperature, high-strength ceramics for uses such as ultra-high-temperature gas turbines, internal combustion engine parts, heat exchangers handling corrosive and erosive material, cutting tools and contact bearings.

(a) Development of beta"-aluminas for use in energy storage and conversion

In-house R&D work on this project element was essentially completed during 1987/88. The main effort was directed to writing up the various aspects of work conducted into the development and characterization of the beta-aluminas and to assisting the two Canadian companies now producing and exploiting these materials: Magna International, Markham {sodium-sulphur battery for electric vehicles} and Almax Industries, Lindsay {thermo-electric generator} as needed.

(b) Development of isotropic hydrogen conductors

The isotropic hydrogen-conducting zirpsios (Nasicons) produced by a proprietary process and reported during the previous year have been provided to Atomic Energy of Canada Ltd. and Ontario Hydro for evaluation for use in steam electrolysis and the pumping of hydrogen and its isotopes. The material has also been provided to a number of research groups in Denmark, Mexico, Italy, Japan, Germany and Israel for other applications including sensors and electrochemical synthesis systems.

During the year, much of the in-house R&D focussed on characterizing the behaviour of electrodes deposited on these materials under operating conditions. This has included the study of cells using impedance spectral analysis and also the development of a computer-controlled system to study electrode behaviour based on capturing and analyzing the transient voltage decay that occurs at both cell electrodes following a current interrupt. From these analyses, it is possible to determine the time constants of the various processes operating at the electrode.

(c) Development of piezoelectrics for NDT transducers

One of the limitations of exploiting ceramics in a high stress field (either electrical or mechanical) is the deleterious effect of microstructural defects such as pores, laminations and microcracks. With the rapidly increasing commercial exploitation of structural ceramics it is becoming increasingly important to qualify products for service. Where very small sub-defects occur (<50 μm), they may be detected and characterized using a high frequency ultrasonic beam.

As a consequence of the much higher brittleness of ceramics, it is necessary to detect defects that are approximately an order of magnitude smaller than those which are critical in metals. However, as with all radiation techniques, the resolution is dependent on the wavelength used to interrogate the specimen and hence there is a need for high resolution transducers for the examination of structural ceramics.

The performance of such transducers depends, in part, on the electrical properties of the piezoelectric ceramic element which is the crucial active component. For high frequency, it is desirable to minimize the dielectric constant and for good signal-to-noise it is desirable to maximize the thickness mode coupling coefficient. To reduce other spurious signals, it is desirable to have effective damping material at the back of the transducer to kill the rear-going signal and to minimize or eliminate the radial coupling to avoid side-going signals.

During the present period, materials based on lead titanate have been synthesized, sintered and electrically and microstructurally characterized. Particular compositions have been developed having a dielectric constant less than 200, with a planar coupling of over 44% and a radial coupling of zero. Through a collaborative program with BM Hi Tech Inc., Collingwood, one of these materials became commercially available at the end of 1987 and transducers operating at a fundamental frequency of 50 MHz that are based on these materials also became available for NDT applications.

(d) Development of tough ceramics

Although ceramics generally have high strength and wear resistance, one of their limitations is brittleness. One of the techniques that has a potential to overcome this problem is to increase their fracture toughness by incorporation of zirconia.

The program to develop zirconia-toughened ceramics for structural applications has continued. This work is conducted both in-house and under contract to Electrofuel Manufacturing Company, Toronto. Several different zirconia-toughened alpha aluminas have been prepared using a variety of starting materials. During the year, increasing commercial interest in this material has become evident. By early 1988, three Canadian companies had expressed interest in commercially developing these materials.

During the year, the in-house program was expanded to also include the development of toughened mullite ($3Al_2O_3.2SiO_2$), a material which is known to have a much improved thermal shock resistance over alpha-alumina. Preliminary data show the modulus of rupture (>300 MPa) of the CANMET-produced material to be the highest ever reported. The collaboration and assistance of members of the former Physical Metallurgy Research Laboratory of CANMET (now the Metals Technology Laboratory) is acknowledged in these programs.

(e) Synthesis of silicon carbide

During the year, the parameters for the synthesis of sub-micrometre beta silicon carbide powder having a high and controlled surface area in the range 10-25 m^2/g have been identified. The material is free of any detectable (to X-ray diffraction) alpha-phase. Batches of 100-200 g of material have been provided to several Canadian companies for their own evaluation.

(f) Development of fine powders

In recent years, there has been a major change in the raw materials used in the ceramics industry - car load quantities of sub-micrometre, very high-purity materials have become commercially available and are used extensively. As part of this trend and indicative of the future is the recent availability of a silicon nitride from Tokyo Soda, Japan produced by the decomposition of the silicon imide.

Currently, such materials are still relatively expensive and their market penetration is limited. However, such materials can have a significant value-added contribution in ceramic processing without being used in bulk to produce monolithic bodies, e.g., as dielectric or structural coatings, very fine powders for joining ceramics and either powders or their precursors for the surface toughening of structural ceramics for increased wear and impact resistance.

Because of these high value-added applications which require the minimum of material, a program was initiated in 1987 to produce "nano" powders by both hydrothermal processing and by the decomposition of organo-metallic precursors. The initial focus of the work is the exploitation of very fine, tetragonal zirconia as a toughening agent in the more common wear-resistant ceramics such as alumina and mullite which have a well-established market of over a billion dollars per year.

(g) Technical support given other departments funding R&D in ceramics

Because of CANMET expertise, technical advice as a scientific authority has been given to various sectors of EMR and NRC for the following contracts:

- Superionic Conduction in Bismuth Oxide	A.K. Kuriakose EMR, RAP
- Development of High-Energy Density Battery	T.A. Wheat NRC, IRAP
- The Toughening and Strengthening of High Performance Ceramics	A.K. Kuriakose
- Hermetic Seal Technology	S.S.B. Wang NRC, IRAP
- Battery Development	T.A. Wheat EMR, IERD
- Development of High Density Advanced Ceramics	T.A. Wheat NRC, IRAP
- Ceramic Powders of Controlled Morphology	T.A. Wheat NRC, IRAP

Contracts:

- DSS 03SQ.23440-5-9117, "Energy efficiency of kilns - Structural clay products fluoride emissions", Pollutech, Ltd., Oakville. S.A.- A.K. Kuriakose.

- DSS 07SQ.23440-5-9186, "Energy conservation in investment casting using Canadian industrial minerals", Designed Precision Castings, Toronto. S.A. - A.K. Kuriakose.

- DSS 06SQ.23340-6-9100, "Development of tough ceramics", The Electrofuel Manufacturing Company, Toronto. S.A. - A.K. Kuriakose.

- DSS 15SQ.23440-6-9102, "High resolution ultrasonic transducers for non-destructive evaluation", BM Hi-Tech Inc., Collingwood. S.A. - T.A. Wheat.

- DSS 01SQ.23340-6-9144, "Analytical interpretation of protonic solid electrolyte/electrode polarization on devices", The Electrofuel Manufacturing Company, Toronto. S.A. - J.D. Canaday and A.K. Kuriakose.

- DSS 01SQ.23440-7-9147, "Current interrupt measurement system", Third Wave Engineering, Ottawa. S.A. - J.D. Canaday.

- DSS 01SQ.23440-7-9023, "Impact of advanced ceramics on Canadian industry-A market perspective", MKM International, Toronto. S.A. - T.A. Wheat.

Publications:

- Kuriakose, A.K., Wheat, T.A., Ahmad, A. and Canaday, J.D. "Poly-crystalline sodium-potassium beta/beta"-alumina"; J. Solid State Chem. 69(2):312-319; 1987.

- Ahmad, A., Wheat, T.A., Kuriakose, A.K., Canaday, J.D. and McDonald, A.G. "Dependence of the properties of NASICONS on their composition and processing"; J. Solid State Ionics 24:89-97; 1987.

- Canaday, J.D., Wheat, T.A., Ahmad, A. and Kuriakose, A.K. "Gas phase relations for protonic solid-electrolyte fuel cells"; J. Appl. Electrochem. 17:545-551; 1987.

- Wheat, T.A. "Advanced ceramics in Canada"; CIM Bull. 43-48; April 1987.

- Canaday, J.D., Wheat, T.A., Kuriakose, A.K. and Ahmad, A. "A polarization model for protonic solid electrolyte fuel cells"; Int. J. Hydrogen Energy 12:3:151-157; 1987.

Reports:

- Kuriakose, A.K., Wheat, T.A. and Hanson, A.J. "Synthesis of silicon carbide"; Division Report MSL 87-28 (OP).

- Kuriakose, A.K., Ahmad, A., Canaday, J.D. and Wheat, T.A. "The effect of composition on the properties of hydronium zirpsios"; Division Report MSL 87-40 (IR).

- Wheat, T.A. "Ceramics in MSL: Challenges and opportunities"; Division Report MSL 87-44 (TR).

- Mirkovich, V.V. "Relation between thermal diffusivity and expansion in an experimental correlation of thermal fragmentation"; Division Report MSL 87-104 (OP&J) Draft.

- Canaday, J.D., Wheat, T.A., Haley, M.P. and Joyce, I.H. "Electrodes for solid electrodes-electrode morphology"; Division Report MSL 87-106 (IR).

- Pouskouleli, G. "Metallorganic compounds as preceramic materials I. Non oxide ceramics"; Division Report MSL 87-122 (J) Draft.

- Canaday, J.D., Kuriakose, A.K., Wheat, T.A. and Ahmad, A. "Polarization of the hydronium-nasicon/platinum interface"; Division Report MSL 87-124 (OP).

- Mirkovich, V.V. "A computerized thermal diffusivity apparatus"; Division Report MSL 87-133 (OP).

- Canaday, J.D., Wheat, T.A., Haley, M.P. and Joyce, I.H. "A morphological investigation of electrodes for solid electrolytes"; Division Report MSL 87-148 (J) Draft.

- Kuriakose, A.K., Wheat, T.A., Quon, D.H.H. and Ahmad, A. "Preparation of zirconia-toughened alumina"; Division Report MSL 87-151 (IR).

- Aota, J., Kuriakose, A.K., Wheat, T.A., Quon, D.H.H. and Wang, S.S.B. "Zirconia-toughened mullite ceramics"; Division Report MSL 87-155 (IR).

- Hanson, A.J. "Dilatometric behaviour of a cold-bonded ceramic"; Division Report MSL 87-159 (TR).

- Wang, S.S.B., Quon, D.H.H., Torrie, G. and Wheat, T.A. "Hydrothermally synthesized zirconia powder - A preliminary study"; Division Report MSL 88-9 (IR).

- Pouskouleli, G. "Metallorganic compounds as preceramic materials II. Oxide ceramics"; Division Report MSL 88-13 (J) Draft.

- Aota, J., Kuriakose, A.K., Wheat, T.A. and Quon, D.H.H. "Fabrication of zirconia-toughened mullite ceramics (ZTM)"; Division Report MSL 88-17 (OP).

- Ahmad, A., Wheat, T.A., Kuriakose, A.K., Quon, D.H.H. and Berry, R. "The effect of processing parameters on the properties of modified lead titanate"; Division Report MSL 88-19 (OP).

- Kuriakose, A.K., Wheat, T.A., Quon, D.H.H., Ahmad, A. and Aota, J. "The effect of precursor raw materials on the tetragonal zirconia content of alumina-zirconia"; Division Report MSL 88-20 (OP).

- Canaday, J.D., Kuriakose, A.K., Wheat, T.A. and Ahmad, A. "Measurements of the platinum/hydronium-nasicon system"; Division Report MSL 88-23 (OP).

Project 30.29.03: Semiconductor Materials for Photoelectrochemical and Catalytic Processes
Project leader : S.M. Ahmed

Objective:

To develop semiconductor catalysts for photochemical and catalytic processes with novel applications: (1) photocatalytic oxidation of pollutants (CN^-, $S_2O_3^{2-}$, SO_3^{2-}, H_2S) on semiconducting TiO_2 suspensions. (2) photoelectrochemical leaching of minerals and selective photocatalytic activation of minerals for flotation.

(a) Photocatalytic and electrolytic production of H_2O_2

Hydrogen peroxide is in increasing demand as an oxidant in extractive metallurgy, e.g., for precipitation of U(VI) from solution and in removal of pollutants such as CN^- and thiosalts. Its use as an oxidant is preferable to other reagents, since it leaves no products other than water and the oxidized pollutant. An economic method of producing H_2O_2, preferably on-site on a relatively small scale, is being sought. Both photocatalytic and electrolytic methods are being developed to meet this demand.

(i) Semiconducting TiO_2 powders doped with Al_2O_3 (5%) were prepared by screen printing by hand and tested in electrode form for the photoelectrochemical production of H_2O_2. The results indicated that the photopotentials developed by TiO_2 electrodes doped with 5% Al_2O_3 were too positive to produce H_2O_2 and powders with lower Al_2O_3 content are needed. Also the electrode properties were not reproducible using manual screen printing. A screen printing machine has been acquired and new compositions will be prepared and tested in the near future.

(ii) The present commercial method of preparing H_2O_2 consists of catalytic reduction of anthraquinone with H_2 in an organic solvent and reacting the products with oxygen to produce H_2O_2. The process has many disadvantages and is not suitable for small scale, on-site production.

Work was conducted to develop an alternate electrolytic method consisting of electrolytic reduction of a quinone in the presence of a proton donor, followed by aeration. H_2O_2 was produced by this method. Further work is being planned to investigate relevant variables and to optimize the process so that its economic potential can be assessed.

(b) Photoelectrochemical studies of semiconducting minerals and application to leaching and flotation

(i) Experimental studies of photoluminescence on GaAs electrodes have led to an understanding of the basic processes of electron-hole recombination at a semiconductor-solution interface which compete with photochemical dissolution of the semiconductor and other charge transfer processes. The data have been interpreted and a paper submitted for publication. The results have proved very useful in understanding the photochemical dissolution and oxidative leaching of the semiconductor minerals.

(ii) The work on photoelectrochemical studies and impedance measurements of specular hematite has been written in two papers and submitted to journals.

(iii) Photoelectrochemical studies of chalcopyrite are being carried out to investigate the role of semiconducting and other solid state properties in the oxidative leaching of this mineral and on its flotation properties. The main objective is to understand the charge transfer mechanism with respect to the energy levels of the semiconductor in relation to the redox potentials of the reagents. Our preliminary results indicate strong influence of the solid state energy levels on charge transfer at the semiconductor-solution interface. The information is expected to provide a better understanding of leaching and flotation practices, so that new and improved methods and better controls can be developed for such processes to achieve better efficiency.

(c) Industrial liaison

The contract with Solarchem Research, Willowdale, Ontario, for the solar chemical production of H_2O_2, supported by the Solar Energy Division of the Renewable Energy Branch, EMR, was extended for the second year to develop a solar reactor and test the H_2O_2 production. This work which is of direct interest to CANMET for the H_2O_2 destruction of CN^-, is being monitored by S.M. Ahmed, who is also serving as a consultant and S.A. to this contract. Solarchem is applying for a patent for their process.

CANMET work on photoelectrochemical properties of semiconducting TiO_2 by S.M. Ahmed has also contributed significantly towards an IRAP project being conducted at Nutech Energy System Inc., London, Ontario, on the photocatalytic destruction of chlorophenols, PCBs and other organic, toxic pollutants.

Reports:

- Ahmed, S.M. Leduc, J. and Haller, S.F. "Photoelectrochemical and impendance characteristics of specular hematite: Part I - Parallel conductance and trap rate studies"; Division Report MSL 87-5 (J) Draft.

- Leduc, J. and Ahmed, S.M. "Photoelectrochemical and impedance characteristics of specular hematite: Part II - Deep bulk traps in specular hematite at small AC frequencies"; Division Report MSL 86-151 (J) Draft.

- Ahmed, S.M., Leduc, J. and Trudel, J. "Studies of the field dependent photoluminescence of n-GaAs electrodes with and without cobalt films"; Division Report MSL 87-73 (OP&J) Draft.

- **Project 30.29.05: Electrodes and Refractories for the Steel Industry**
  Project leader : T.A. Wheat

Objective:

To determine the nature and mechanisms of refractories failure under steel-making conditions as an aid in material selection and/or operation modifications to enable most cost beneficial processing. To report on specifications of modified or alternative materials to the steel producers.

The corrosion resistance of four types of magnesia-carbon bricks with 15 to 24% carbon in contact with slags at 1650 °C in an argon atmosphere was investigated. Retardation of slag penetration owing to the presence of graphite was demonstrated. Based on the chemical-structural profiles results, it has been shown that the corrosion resistance of the refractories is dependent on the slag composition, and decreases with the basicity of the slag. The loss of magnesium by vapourization/sublimation augmented by reduction of MgO in contact with graphite was not observed as previously reported for tests conducted in vacuum. In contrast with the behaviour under vacuum, no loss of MgO from the system occurred by vapourization/sublimation under an argon atmosphere. However, it was found that the high lime slag reacts with the carbon to form calcium carbide and this removal of carbon from the refractory accelerates its degradation.

With the cooperation of Canadian Steel Foundry, the mechanisms of refractory nozzle and nozzle stopper blockage during steel-casting were investigated. The fusion of the nozzle and stopper has been attributed to the formation of liquid phase in the boundary between the nozzle and stopper resulting from the interaction between the refractories and the steel melt.

Reports/Publications:

- Quon, D.H.H. and Bell, K.E. "Performance of magnesia-carbon bricks in vacuum at high temperature"; J. Can. Ceram. Soc. 56:39-44; 1987.

- Quon, D.H.H., Wang, S.S.B., Aota, J. and Wheat, J.A. "Corrosion resistance of dolomite bricks in contact with slags"; Division Report MSL 87-147 (OP&J) Draft.

- Wang, S.S.B., Quon, D.H.H. and Aota, J. "Degradation of magnesia-carbon bricks in argon atmosphere at high temperature"; Division Report MSL 87-152 (IR).

Treatment - Industrial Minerals

- **Project 30.37.01: Performance and Durability of Concrete Incorporating Supplementary Cementing Materials**

Project leader : V.M. Malhotra

Objective:

To develop data on mechanical and elastic properties and durability of portland cement and portland cement concrete incorporating up to 65% less energy intensive materials, such as granulated blast furnace (B.F.) slag, fly ash, silica fume and limestone dust for applications in Canadian marine environments and in acidic waters of Northern Canada; to develop a database on portland cement concrete and portland cement/B.F. slag/fly ash concretes for industrial application involving exposure to sustained temperatures in the range 75-450 °C for periods up to six months; to produce a low cost asbestos cement cooling tower fill resistant to corrosion in extreme environmental conditions such as freezing and thawing, soft and brackish waters, corrosive water and abrasion.

To conserve resources and energy it is imperative that less costly and less energy intensive materials be used in the production of portland cement and portland cement concrete. The most promising of the less energy intensive materials for replacing cement are granulated slag, fly ash and silica fume. The energy required to produce granulated slag is estimated at only 25% of that for portland cement, and fly ash and silica fume are industrial byproducts. As slag and fly ash from different sources have unique properties depending upon the raw materials used, it is essential that investigations be performed to obtain long term performance data on their use, with and without high-range water reducers, in concrete under Canadian climatic conditions.

Investigations were continued both in-house and under contract to develop a data bank on the engineering and thermal properties of high-volume fly ash concrete using different cements and different percentages of fly ash and cement. Test results indicate that cement factors beyond 200 kg/m^3 are not very cost effective in this system. Three large concrete blocks, 3 x 3 x 3 m in size, were cast in Halifax to monitor the long term performance of the reference and high volume fly ash concrete.

Studies performed under contract have indicated that there was retrogression in strength of high-strength silica fume concrete. In order to confirm this comprehensive investigation studies were commenced to determine long-term (>5 years) performance of silica fume in high-strength concrete (>12,000 MPa). A large number of test prisms and cylinders were cast for long-term strength development under moist- and air-curing conditions.

A comprehensive book entitled, "Supplementary Cementing Materials" was published as a special CANMET publication (SP 86-8E). The book contains in depth articles on natural pozzolans, silica fume, fly ash and slag.

The IRDC/CANMET project on blast-furnace slags was initiated. The purpose of the program is the development of a data base on ground granulated blast

furnace slags and to train engineers from Argentina in the use of granulated blast furnace slags. Under the program, a CANMET engineer visited Argentina for a period of one week. A scientist from Argentina will start work at CANMET in April 1988 for a period of six months.

Chemical analysis, glass content, particle size distribution, heat evolution rate and total heat evolved, scanning electron micrographs and strength development were studied for three granulated blast furnace slags of different origin and two fly ashes of high and low CaO content. At all ages, heat evolution rates and total heat evolved by the fly ashes were lower than the corresponding values for the granulated blast-furnace slags, regardless of origin.

An investigation was completed to determine the chloride ion permeability of concrete incorporating supplementary cementing materials, employing the rapid chloride permeability test. The supplementary cementing materials employed included silica fume, ground granulated blast-furnace slag and fly ash. The test results showed that the use of supplementary cementing materials reduced significantly the chloride permeability of concrete.

Studies were completed to determine the combined effect of de-icing salts and repeated cycles of freezing and thawing on concrete incorporating granulated/pelletized blast-furnace slags. Regardless of the percentage and the type of the slag used, the concrete incorporating slags exhibited considerably more surface scaling than the reference concrete. This was, in spite of the fact that both concretes had adequate air-void spacing factors.

Several investigations dealing with alkali-aggregate reactions in concrete are in progress and several reports have been published or are being processed. Investigations dealing with the survey and evaluation of the rock types in New Brunswick, Nova Scotia and Newfoundland which may be potentially reactive are in progress, but it is early to draw any conclusions.

A post-doctoral fellow commenced his duties in December, 1987 and is in the process of initiating a two-year study on the evaluation of a number of different accelerated methods for determining alkali aggregate reactivity in concrete.

The first phase of the investigation dealing with determining the effect of high temperatures on silica fume concrete was completed, and a report is under preparation. In general at the temperatures investigated, i.e., 150 to 450 °C, the performance of silica fume concrete is comparable to that of reference concrete.

Exploratory studies were commenced to identify means of activating ground granulated blast-furnace slags. The materials being investigated include sodium silicates with and without silica fume or lime. Currently, the investigation is being limited to the determination of compressive strengths on mortar cubes. If promising, the investigation will be extended to concrete.

A round-robin program to determine the utilization of ground granulated blast-furnace slag in mine backfill operations was completed. Four mines

from the Sudbury basin participated in the program, test data are being analyzed and a technical paper will be prepared.

Contracts:

- Reqn. 4-9236 MDA, "Study of the alkali reactivity of potential concrete aggregates of New Brunswick", ADI Ltd. S.A. - J.A. Soles.

- Reqn. 5-9255 MDA, "Study of the alkali reactivity of potential concrete aggregates of Newfoundland", Golder Associates. S.A. - J.A. Soles.

- Reqn. 6-9157 MDA, "Study of the alkali reactivity of potential concrete aggregates of Nova Scotia", Jacques Whitford and Associates. S.A.- J.A. Soles.

- Reqn. 4-9041, "Reproducibility of a new technique for measuring the permeability of concrete - Phase III", Laboratoire de Béton. S.A.- G.G. Carette.

- Reqn. 4-9171, "Low permeability high strength fibre reinforced normal weight concrete for offshore structures", Lafarge Canada Inc. S.A.- G.G. Carette.

- Reqn. 4-9308 MDA, "Development of engineering on Nova Scotia fly ashes", L.A. Shaw Ltd. S.A. - G.G. Carette.

- Reqn. 6-5321, "Determination of air-void parameters of hardened portland cement concrete - Part II", Laval University. S.A. - G.G. Carette.

- Reqn. 6-9014, "Creep studies on portland cement/slag concretes", University of Calgary. S.A. - G.G. Carette.

- Reqn. 6-9201, "Determination of air-void parameters of hardened portland cement concrete - Part I of round-robin test program", Dr. Brian Hop, Consultant. S.A. - G.G. Carette.

- Reqn. 7-9062, "Creep studies on high-strength normal weight concrete", University of Calgary. S.A. - G.G. Carette.

- Reqn. 7-9146, "Long-term strength development of high-strength field concrete containing silica fume and other supplementary cementing materials", Trow Ltd. S.A. - G.G. Carette.

- Reqn. 7-9217, "Mercury porosity tests on mortar samples using Carlo Erba equipment", University of Sherbrooke. S.A. - G.G. Carette.

- Reqn. 6-9156, "Evaluation of blast-furnace slag for possible use as an additive to mine backfill", Watts Cement. S.A. - E. Douglas.

- Reqn. 6-9156, "Evaluation of blast-furnace slag for possible use as an additive to mine backfill", Watts Cement. S.A. - E. Douglas.

- Reqn. 4-9156, "Development of an asbestos-cement cooling tower fill for thermal generating plants", Atlas Turner Inc. S.A. - E. Douglas.

- Reqn. 7-9137, "Thermal properties testing of concrete incorporating supplementary cementing materials", Geotherm Inc. S.A. - V. Sivasunderam.

- Reqn. 7-9139, "Creep studies of high-volume fly ash/slag concrete", Canada Cement Lafarge. S.A. - V. Sivasunderam.

- Reqn. 7-9129, "Diatomite in Nova Scotia as pozzolanic material", W. Langley and Associates. S.A. - H.S. Wilson.

- Reqn. 4-9212, "Development of cementitious grout for post-tensioned concrete members for use in offshore structures", Levelton and Associates. S.A. - H.S. Wilson.

Reports:

- Malhotra, V.M. "Superplasticizers, pozzolans and granulated blast-furnace slags in concrete"; Division Report MSL 87-17 (OP&J) Draft.

- Douglas, E., Elola, A. and Malhotra, V.M. "Characterization, conduction calorimetry, microstructure and properties of ground granulated blast-furnace slag and fly ashes"; Division Report MSL 88-18 (OP&J) Draft.

- Malhotra, V.M. "Supplementary cementing materials"; CANMET Special Publication 86-6E.

- Giaccio, G.M. and Malhotra, V.M. "Mechanical properties and freezing and thawing resistance of high-volume fly ash concrete made with ASTM Types I and II cements"; Division Report MSL 87-112 (OP&J) Draft.

- Sivasunderam, V., Carette, G.G. and Malhotra, V.M. "Superplasticized high-volume fly ash system to reduce temperature rise in mass concrete"; Division Report MSL 87-83 (OP&J).

- Malhotra, V.M. and Painter, K.E. "Early-age strength properties, and freezing and thawing resistance of high-volume fly ash concrete"; Division Report MSL 87-113 (OP&J) Draft.

- Malhotra, V.M., Wilson, H.S. and Painter, K.E. "Resistance of concrete incorporating silica fume at elevated temperature"; Division Report MSL 87-126 (OP&J) Draft.

• Project 30.37.02: Concrete for Offshore Structures
Project leader : V.M. Malhotra

Objective:

To develop engineering data on high strength, low permeability, and high impact resistance concrete and grouts for offshore structures; to develop concrete permeability and ice abrasion resistance and NDT monitoring inspection tests.

Oil exploration and production activities in the offshore arctic environment are expected to increase in the near future. It is anticipated that many of the offshore structures will be constructed of concrete. At present there are many unknown factors related to the performance of concrete structures in the arctic environment. The extreme cold adversely influences the properties of concrete. The ice creates additional problems of abrasion and impact. It is therefore essential that studies be performed to develop concretes which will be durable in the arctic environment. Such concrete should have high strength, low permeability and low unit weight. Also, testing methodology should be developed to determine abrasion resistance and permeability of these special concretes.

Limited investigations were commenced to determine the effect of cover on the corrosion of the reinforcing bars in concrete under offshore exposure conditions. Large test prisms were cast with different cover-to-steel depths. These were then transported to Treat Island, Maine for long-term exposure to the action of marine environment. The first monitoring of the test prisms will be performed in June 1988.

The ninth yearly inspection of test prisms installed at Treat Island was performed. Visual checks were made and photographs were taken. A display and a report were prepared, and presented at the Mathers Conference on Durability of Concrete held in Atlanta in 1987.

Modifications were made (under contract), by Arctec Canada Ltd. to the test machine to determine resistance of concrete to ice abrasion and impact. The purpose of the modifications was to reduce time of testing. Following the modifications, Arctec Canada Ltd. performed a series of tests on concrete cylinders for Mobil Oil Ltd., Dallas, Texas. The machine is the only one of its kind in the world. Additional testing is planned for concretes incorporating supplementary cementing materials. A paper on the development of the machine has been prepared for presentation at the 2nd International Conference on the Performance of Concrete in Marine Environment to be held at St. Andrews, N.B. in 1988.

In 1986, 12 high-strength concrete panels 150 x 330 x 3660 mm in size were installed on the side of an existing dock at Nanisivik in Baffin Island to determine long-term effects of abrasion and impact on different types of concretes. Due to the lack of funds, no monitoring of the panels was done in 1987. The monitoring is planned for 1988.

Contracts:

- Reqn. 6-9174, "Utilization of Newfoundland aggregates to produce high-strength concrete for offshore structures - Phase I", Nolan Davis Ltd. S.A. - M. Bilodeau.

- Reqn. 7-9240, "Utilization of Newfoundland aggregates to produce high-strength concrete for offshore structures - Phase II", Nolan Davis Ltd. S.A. - V.M. Malhotra.

- Reqn. 4-9041, "Reproducibility of a new technique to measure the permeability of concrete", Laboratoire de Béton Ltée. S.A. - G.G. Carette.

- Reqn. 4-9246, "Evaluation of the suitability of existing repair materials to deal with potential types of damage", Ontario Hydro. S.A.- H.S. Wilson.

- Reqn. 7-9128, "Determination of the resistance of concrete to abrasion and impact by ice: modifications to the testing machine and development additional test data - Phase II", Arctec Canada. S.A. - V.M. Malhotra.

- Reqn. 7-9044, "Long-term durability studies at Treat Island: 1987 monitoring and evaluation of test programs", University of New Brunswick. S.A.- G.G. Carette.

- Reqn. 7-9050, "Durability of reinforced concrete in marine environment", University of New Brunswick. S.A. - G.G. Carette.

- Reqn. 6-9072, "Design and construction of automated freeze-thaw testing equipment for concrete", (unsolicited proposal UP-A-470), Arctec Canada.

Reports:

- Wilson, H.S. and Malhotra, V.M. "Development of high-strength lightweight concrete for structural applications"; Division Report MSL 87-11 (OP&J) Draft.

- Malhotra, V.M. "CANMET investigations in the development of high-strength lightweight concrete"; Division Report MSL 87-33 (OP&J).

- Bisaillon, A. and Malhotra, V.M. "Permeability of concrete using a uniaxial water-flow method"; Division Report MSL 87-119 (OP&J) Draft.

Biotechnology

- **Project 30.45.01: Bioprocessing**
  Project leader : R.G.L. McCready

Objective:

To identify, quantify, test and apply biological phenomena to improve mineral processes for the recovery of metal values, to enhance recovery of fossil fuels, and to reduce the environmental impact of industrial operations in these fields to acceptable levels.

(a) Bacterial leaching of sulphide ores

The objective is to develop an economically viable biohydrometallurgical process to extract and recover secondary metal values from sulphide ores, specifically those portions of mineral deposits which are left underground for mine support or which are below cut-off grade for conventional mining.

Typically 30% of mineral deposits are left untouched in most mining operations. Treatment of such residual resources by bacterial leaching would enable complete utilization of ore reserves.

Projects in this are to include a demonstration of underground leaching of uranium and pilot plant studies on the bioleaching of a complex sulfide ore to recover copper and zinc. In 1987, Denison Mines produced greater than 800,000 lbs of U_3O_8 by bacterial leaching.

(b) Heterotrophic leaching

The objective is to determine the effectiveness of heterotrophic leaching for the extraction of Ni, Co and other base metals from low grade or refractory ores.

Some ores are not amendable to bacterial leaching by autotrophs or the recovery of the metal from a solution containing high concentrations of iron is difficult. If such ores could be leached economically under neutral or alkaline conditions, the metal of interest may be preferentially solubilized without iron solubilization occurring, thereby making recovery of the metal from solution much easier.

About 30 microbial metabolites have been assessed for their ability to preferentially leach Ni from pentlandite. One group of metabolites is very effective in solubilizing Ni and Co without solubilizing iron at an alkaline pH. Studies are continuing to assess the effects of metabolite concentration, pH, temperature and leaching with combinations of two or more metabolites.

(c) Preferential and sequential leaching of a complex sulphide ore

The objective is to determine the sequence of bioleaching of a complex sulfide ore, with a view to obtaining a better understanding of the mechanism of oxidation of metal sulphides by Thiobacillus ferrooxidans.

The sequence of leaching observed to date is pyrrhotite > cubanite > sphalerite > chalcopyrite > pyrite.

Contracts:

- Reqn. 6-9126, "Determination of activity parameters in Thiobacillus ferrooxidans strains as criteria for mineral leaching efficiency", Dept. of Microbiology, University of Manitoba. S.A. - R.G.L. McCready.

- Reqn. 6-9159, "Development of thermophilic biohydrometallurgy to enhance precious metal extraction", Coastech Research Inc. S.A. - R.G.L. McCready.

- Reqn. 6-9197, "Research study to determine the source of oxygen during bacterial oxidation of mineral sulphides", Department of Physics, The University of Calgary. S.A. - R.G.L. McCready.

- IRAP Project CA-910-786-A, "Underground biological in-place leaching of uranium ore - Phase II", Denison Mines Ltd. S.A. - R.G.L. McCready.

- Manitoba MDA Agreement: Hudson Bay Mining and Smelting, The University of Manitoba and the Ontario Research Foundation have continued to perform pilot scale tests for the bacterial leaching of a complex sulfide ore and the recovery of copper and zinc from solution. S.A. - R.G.L. McCready.

(d) Biological unit operations

Objective:

To identify, quantify and apply biological phenomena which enhance performance of unit operations used in the Mineral Processing and Mineral Resource Extraction Industries.

Projects in this area include the bioadsorption of metals from process solutions or effluents, the microbial degradation of organics which interfere with mineral recovery from ores or concentrates, the microbial recovery of metals from mill effluents and biological mitigation of acid mine drainage.

Contracts:

- Reqn. 5-9156, "Microbial control of tailings dump leaching", Department of Biology, The University of Ottawa. S.A. - W.D. Gould.

- Reqn. 6-9052, "Optimization of fungal adsorption of uranium and cell immobilization and pelletization", Acres Davy McKee, Engineering Inc. S.A. - R.G.L. McCready.

- Reqn. 6-9103, "Microbial degradation/alteration of carbonaceous species in Canadian ores and concentrates, Phase II", Witteck Development Inc. S.A.- R.G.L. McCready.

- Reqn. 6-9118, "Growth dynamics of naturally colonizing characeae in abandoned tailings ponds", Boojum Research Ltd. S.A. - R.G.L. McCready.

- Reqn. 6-9164, "Use of biomass to recover uranium from bioleach solutions", McMaster University. S.A. - R.G.L. McCready.

- IRAP Project L2730-1064, "Biorecovery of selenium", CMS Rotodisk. S.A.- R.G.L. McCready.

- IRAP Project CA910-6-1078 - Chara Process, "Biological polishing of alkaline effluents", Boojum Research Ltd. S.A. - R.G.L. McCready.

• Project 30.45.03: Biotechnology Networking
Project leader : R.G.L. McCready

Objective:

On a continuing basis to maintain and expand a network to improve the interaction and communication between the research community and Canadian Industry, and to improve the availability and accessibility of relevant information.

Personnel from MSL:

1. Prepared and published four BIOMINET (Mineral Leaching and Metal Recovery Network) Newsletters to keep members aware of current research projects and developments in the application of biotechnology in the mineral industry.

2. Organized, prepared and presented a two-day workshop on "Basic Microbiology for the Mineral Industry" on November 5 & 6 which was attended by 24 participants. CANMET SP 86-7.

3. Participated in a Symposium on "Biotechnology in the Petroleum Sector" as part of the Canadian Society of Microbiologists' Annual Meeting in Toronto.

4. Published the BIOMINET Proceedings from the 1986 Annual Meeting. CANMET SP 86-9E.

5. Organized and participated in the Annual BIOMINET Meeting which was attended by 30 members at Laurentian University, Sudbury, Ontario.

6. Participated in the Biotechnology Session of the CIM Annual Meeting in Winnipeg. Division Report MSL 87-105 (OP).

7. Participated in the 8th International Symposium on Biohydrometallurgy, Warwick, U.K. Division Report MSL 87-77 (OP).

8. Participated in the Workshop on Acid Generation in Mine Tailings, Val d'Or, Quebec. Division Report MSL 87-62 (OP).

9. Invited Seminar at the Dept. Chem. Eng., Univ. of Saskatchewan.

10. Participated in a Workshop on Acid Mine Drainage, Halifax, N.S. Division Report MSL 87-3 (OP&J).

11. Published "Biotechnology Bibliographies. SP 86-2.

BIOMINET database:

New organizations were added to the BIOMINET database as survey responses continued to arrive. Many address changes and deletions were required; mailing labels are produced as required.

Extraction - Metallics

- **Project 30.52.02: Chloride Processes for Sulphide Ore Treatment**
  Project leader : D.H. Bell

Objective:

To develop and evaluate viable chloride metallurgical processes which will achieve the goals of metal recoveries above 90% and the elimination of SO_2 emissions by yielding elemental sulphur or stable sulphides from bulk sulphide concentrates.

Although New Brunswick has the largest reserves of zinc, lead and silver in Canada, the complexity of these sulphide orebodies has resulted in inefficient recovery of high-value saleable products using existing technology. To improve metal extraction efficiency it is necessary to produce a bulk concentrate, however, because of the complexity and relatively low grade of the bulk concentrate, it is not amenable to treatment by conventional processing technology. CANMET has been investigating and evaluating chloride processes for the treatment of these complex sulphide concentrates. Work at CANMET and under contract has largely confirmed the basic flowsheet for a ferric chloride leach process. Current activities relate to the further development of process steps in the ferric chloride leach process, to studies of the electrowinning of copper from aqueous chloride electrolytes and to studies of dissolution rates of metallic sulphides in chloride and sulphate media.

Increasing concern over "acid rain" may in the future result in the enforcement of SO_2 emission-limiting regulations. Processes which yield elemental sulphur instead of SO_2 are potentially viable alternatives to conventional technology. Chloride technology offers such a process, however industrial

acceptance will be predicated on the demonstration of technical and economical viability.

(a) The Ferric Chloride Leach (FCL) process

The FCL process has been developed, both within CANMET and by contract research, into a technically viable process which meets the objectives of 90% metal recovery and elimination of SO_2 emission. The process appears to be economically competitive with, and perhaps superior to, conventional technology. The flowsheet which has resulted from CANMET development work is shown in Fig. 2. An economic and technical evaluation will be done under contract during the 1988/89 fiscal year to allow CANMET to fully appraise the potential of the process, and if warranted identify possible industrial partners.

A report on the FCL process has been issued providing a preliminary economic assessment.

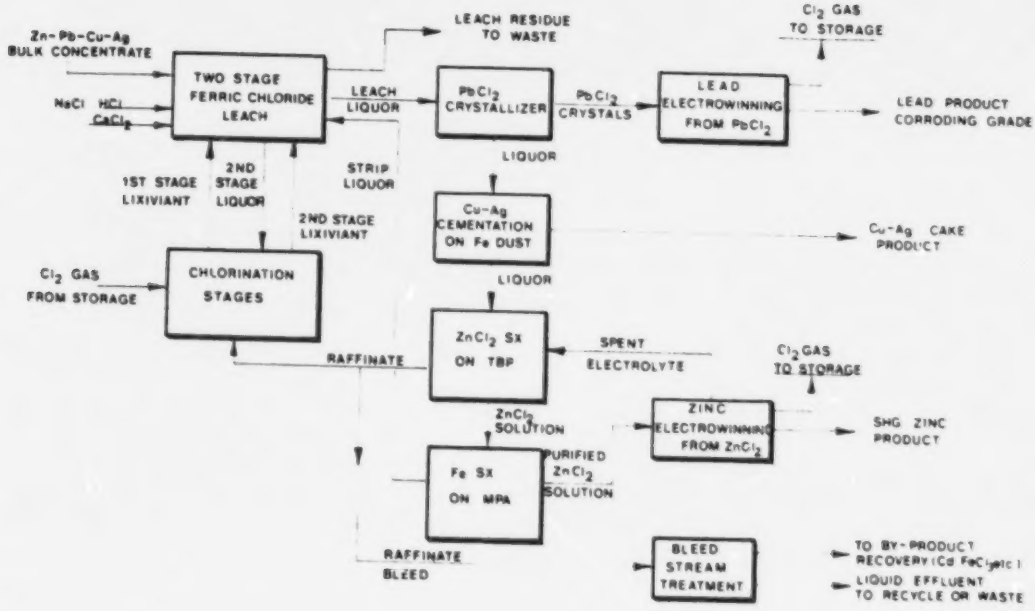

Fig. 2. The CANMET ferric chloride leach process

(i) Leaching: FCL process development

A two-stage leach of a pyritic bulk concentrate at 0.11 M HCl and 6.0 h retention time resulted in Pb, Zn, Cu and Ag extractions of 99.5%, 99.2%, 97.9% and 96.9%, respectively. The experimental results indicated that 15% pyrite dissolution occurred and 50% of the HCl consumption (25 g/kg of concentrate) was due to the siderite fraction in the concentrate.

The leach liquor with pH about 1 was amenable for subsequent product recovery operations.

(ii) $PbCl_2$ recovery and cementation of Cu and Ag

$PbCl_2$ crystals were recovered from the $FeCl_2$ leach liquor by cooling. The washed $PbCl_2$ crystals contained less than 1% of the Ag leached and less than 400 ppm total impurities.

Soluble Cu and Ag values were reduced to 1 mg/L each by two-stage cementation using scrap and then granular iron. Work continues towards optimization of $PbCl_2$ recovery and continuous cementation.

(iii) Solubility of lead chloride in ferric chloride leach solutions

The solubility of lead chloride in ferric chloride leach solutions has been extensively studied. Data compression and systems modelling studies to interpret the experimental results are in the final stages for external publications. Literature data on chloride activity coefficients at different temperatures and solution composition are being evaluated.

(iv) Chlorination and oxidation of leach solutions

A paper on the chlorination of $FeCl_2$ leach solutions was accepted for publication in Can. J. Chem. Eng.: Division Report MSL 87-60 (J). Pressure oxidation studies with oxygen are in progress. The precipitation of iron is mainly controlled by the initial acid and ferrous concentrations, but the reaction temperature >100°C also plays a major role. A progress report on this study is being prepared.

(v) Solvent extraction - zinc chloride solution purification

The solvent extraction circuit for zinc using TBP has been further developed. A solvent extraction system was identified for removing the residual iron in the Zn circuit strip liquor down to the levels required for the electrowinning step. This iron extraction step has been tested in an initial pilot-plant run. Concentration targets were met for the iron removal. An iron strip liquor containing 50 g Fe/L in chloride is produced and this solution is suitable for recycle to the leach circuit. Some problems encountered with phase separation and precipitates are being controlled using organic phase modifiers and these will be tested in a laboratory scale pilot-plant test.

(vi) Solvent extraction - infrared spectroscopy

Some materials from studies on solution purification by removal of Fe(III) by solvent extraction were examined by Fourier transform infrared spectroscopy. Cruds from mono-2-ethylhexyl phosphoric acid (MEHPA) solvent extraction systems were examined and identified as iron MEHPA polymeric materials. Cruds were compressed, dissolved in CCl_4 and cast as films on AgCl windows.

(b) Leaching of metals and sulphide minerals

(i) Zinc minerals

The effect of the iron content of pure, sized natural sphalerites on the rate of dissolution in $FeCl_3$-HCl and $Fe_2(SO_4)_3$-H_2SO_4 media is being examined. Increasing iron content increases the rate of sphalerite dissolution, and the effect is most pronounced for iron contents in the 0-2% range. Increasing iron contents in the 2-14% range have only a modest effect on sphalerite dissolution. High-iron sphalerites leach about an order of magnitude more rapidly than very low-iron sphalerites. Similar effects are noted in both the chloride and sulphate systems. It is believed that the iron content affects the conductivity of the sphalerite that in turn impacts on the rate-controlling electrochemical process.

(ii) Copper electrowinning from aqueous chloride electrolyte

One of the main problems encountered in copper electrowinning from chloride electrolyte ($FeCl_2$-NaCl-HCl) is the product contamination with silver. Silver values are economically lost and the copper product is of inferior quality. Conventional conditioning of the electrolyte by pre-electrolysis or cementation is not an effective method of treatment. The use of CuI additions to control silver concentrations to below 1 mg/L in the electrolyte was studied under a variety of conditions. The method gives electrolyte silver concentration of 2 mg/L from the original 25-90 mg/L electrolytes in a single stage.

A report describing the electrowinning of particulate copper from aqueous chloride electrolyte has been issued (MSL-INT 87-7). Testwork is currently underway to determine the deportment of impurities (As, Sb, Bi and Pb) during copper electrowinning from aqueous chloride electrolyte using a simplified diaphragm cell.

Reports:

- Tan, K.G. and Bedard, P.L. "Development of a mini-plant chlorinator for ferric chloride leach process"; Division Report MSL 87-60 (J) Draft.

- Tan, K.G. "Modernized hydrometallurgical process development techniques"; Division Report MSL 87-68 (OP&J).

- Morrison, R.M. "The dissolution of silver in ferric sulphate-sulphuric acid media"; Division Report MSL 87-46 (J) Draft.

- Bell, D.H. "The CANMET ferric chloride leach process"; Division Report MSL 87-157 (TR).

- **Project 30.52.04: Plasma Reactors**
  Project leader : J.M. Skeaff

Objective:

To investigate and develop applications of plasma technology in the fields of energy utilization and pyrometallurgy as a means of increasing energy use efficiencies and of substituting electricity for fossil fuels.

Plasma technology has the potential in many instances for the efficient substitution of electrical energy for fossil fuels utilization as well as for completely new applications. It is also evident that plasma technology has developed to the state where applications on an industrial scale are being seriously considered, are planned or are a reality. However, Canada, although possessing more than adequate supplies of relatively inexpensive electricity, lags behind the development of industrial plasma technology. To assist in the development of these applications, CANMET has accepted the lead agency role in the field within the Federal Government.

(a) Plasma technology in metallurgy

Further tests with a mixture of hematite, coke and lime were conducted in order to better define the operating characteristics of the 100 kVA plasma reactor. These tests were relatively successful in terms of quickly achieving a continuous, uninterrupted arc at steady state operation as well as producing kilogram quantities of pig iron. However, the tests also uncovered some potential problem areas, such as the difficulty in measuring local temperatures in the furnace hearth itself and the dissolution of the refractory walls into the slag.

Advanced ceramics in the form of carbides, nitrides, silicides and oxides are now being used in the production of materials with thermal, mechanical, electrical and chemical characteristics superior to those produced conventionally. The processing of these compounds often requires ultra high temperatures and highly controlled conditions. A literature review on the production of silicon carbide powders by thermal plasma was undertaken and discussions were held with scientists involved in this field in universities and government. Contract work on this subject is now being done at the University of Sherbrooke, Quebec. An investigation into the production of titanium silicides and titanium-iron-silicides is also underway at Queen's University.

A contract has also been awarded to investigate a process for the direct smelting of sulphide ores to produce elemental sulphur.

(b) Contracts:

- Reqn. 7-9180, "Plasma synthesis of ultrafine silicon carbide powders", M. Boulos, University of Sherbrooke. S.A. - S.A. Mikhail.

- Reqn. 7-9196, "Plasma production of titanium silicides and titanium-iron-silicides", C. Pickles, Queen's University. S.A. - C.A. Hamer.

- Reqn. 6-9189, "Investigation into the feasibility of direct reduction and smelting of sulphide ores in an LB furnace", W.K. Lu, McMaster University, Hamilton. S.A. - J.M. Skeaff.

(c) N.R.C. contribution arrangement

- Reqn. 5-0870, "D.C. plasma arc furnace", R.S. Crawley, INCO Ltd., Toronto. S.A. - J.M. Skeaff.

• Project 30.52.05: Impurities in Copper Refining
Project leader : J.E. Dutrizac

Objective:

In co-operation with the Canadian copper industry, to develop, by 1990, improved technologies for the characterization, deposition, control and processing of impurities in electrolytic copper refining.

Canada is a major producer of primary copper, and all the nation's primary copper is produced by smelting. During smelting, many of the impurities contained in the copper concentrates are collected in the blister copper smelter product. It is necessary to remove such impurity elements from the blister copper both to meet market requirements for copper conductivity and to recuperate valuable byproducts. Electrorefining in a $CuSO_4$-H_2SO_4 electrolyte is universally used for this purification. The issue of impurity control is of concern to all producers as it impacts directly on tankhouse operation and the profitability of the entire plant. Most of the Ag, Au, Se and Te form insoluble products (anode slimes) during electrorefining. Although anode slimes have been processed for over a century, much remains unknown about this process, and the problems associated with anode slimes are expected to intensify. If the Canadian smelting industry is to remain viable in the face of keen international competition, technological responses must be developed to overcome current problems.

(a) Characterization of copper anodes and anode slimes

Carefully selected impurity-free areas of commercial anodes were examined by the proton microprobe at the Max Planck Institut fur Kernphysik (Heidelberg) and by the ion microprobe at Surface Science Western (London). The proton microprobe results indicate that number of elements such as As (to 200 ppm), Ag (to 1300 ppm), Pb (to 580 ppm) and Au (72 ppm at the detection limit) may be present in solid solution in the Cu matrix. Single-element specific analyses by the ion microprobe have confirmed the Au content of the copper matrix in four commercial anodes with a sensitivity of better than 1 ppm Au.

Detailed mineralogical studies have been carried out on a number of anodes and anode slimes from Canada's three copper refineries. The anodes, raw anode slimes and sulphation reactor slimes at Inco's Copper Cliff copper refinery were studied in detail, and the behaviour of Ni, Se and Te was

elucidated. The presence of silicate phases is a new finding with commercial implications. The raw anode slimes from the three copper refineries were compared and a paper was presented on this topic. It was shown that silver dissolves during electrorefining but that the dissolved silver was immediately reprecipitated in a variety of forms.

(b) Anode passivation

The effect of the impurities O_2, Ag and Se on the passivation of copper anodes is being studied using cyclic voltammetry; the slimes produced during polarization are being analyzed by SEM-EDX and XRD techniques. In all cases the passivation time decreased with an increase in the impurity content of the copper anodes.

More accurate measurements are required to determine if discontinuities in the solubility of copper sulphate in commercial electrolyte occur as a function of temperature and solution acidity. Analytical methods that allow the determination of trace amounts of As, Sb, Ag and Si in tankhouse electrolytes are being developed.

(c) Arsenic in copper refining

The presence of arsenic in copper anodes can reduce anode passivation and improve cathode quality. A study was completed that shows it is possible to electrowin a copper arsenide product suitable for doping anode copper. Copper arsenide deposits containing up to 40% As were electrowon and the As content increased with increasing current density and As/Cu ratio. Arsine gas evolution did not occur at normal operating potentials.

(d) Alternate technologies

A novel ammoniacal pressure leaching process was developed for copper refinery anode slimes, and a patent application has been filed. Testwork was done using both Kidd Creek and Inco slimes.

An EMR Research Agreement (No. 169/02/57) with Professor W.C. Copper of Queen's University will critically review anode slimes treatment options.

Contracts:

- Reqn. 5-9109, "Development of an improved method for monitoring the composition of electrolyte in the copper refinery", Inco Ltd. S.A.-D.J. MacKinnon.

Patent Application:

- Tan, K.G., Bedard, P.L. and Weatherell, C.J. "Selective ammonical pressure leaching process"; Can. Patent Appl. No. 5556372; January 12, 1988.

Reports:

- Morrison, M. and MacKinnon, D.J. "Literature survery on the electrodeposition of copper-arsenic alloys"; Division Report MSL 87-25 (LS).

- Chen, T.T. and Dutrizac, J.E. "Application of electron microscopy to the electrorefining of copper"; Division Report MSL 87-54 (J) Draft.

- Tan, K.G. "Fulminating gold and silver"; Division Report MSL 87-59 (J).

- Chen, T.T. and Dutrizac, J.E. "Mineralogical characterization of anode slimes: Part 1 - Anode copper from Inco's Copper Cliff copper refinery"; Division Report MSL 87-72 (J) Draft.

- Dutrizac, J. and Chen, T.T. "A mineralogical comparison of the anode slimes from three Canadian copper refineries"; Division Report MSL 87-84 (J).

- Chen, T.T. and Dutrizac, J.E. "Mineralogical characterization of anode slimes: Part 2 - Raw anode slimes from Inco's Copper Cliff refinery"; Division Report MSL 87-87 (J) Draft.

- Chen, T.T. and Dutrizac, J.E. "Mineralogical characterization of anode slimes: Part 3 - Sulphation reactor slimes from Inco's Copper Cliff copper refinery"; Division Report MSL 87-88 (J) Draft.

- Cabri, L.J. "Applications of proton and nuclear microprobes in ore deposit morphology and metallurgy"; Division Report MSL 87-110 (OP&J).

- MacKinnon, D.J. and Morrison, R.M. "The electrowinning of copper arsenide"; Division Report MSL 87-165 (TR).

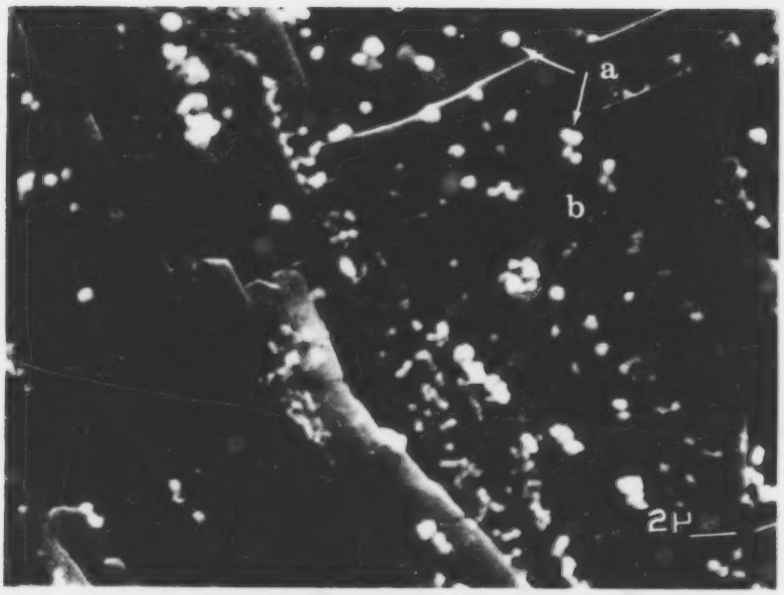

Fig. 3. SEM micrograph which shows the deposition of silver crystals on copper sulphate crystals formed during the electrorefining of copper. The implication is that silver is reduced by dissolved cuprous ion. (a) - metallic silver, (b) - $CuSO_4.5H_2O$ crystals formed on the copper anode

Extraction - Rare Metals

- **Project 30.61.01: Uranium Process Development**
  Project leader : G.M. Ritcey

Objective:

To effect significant improvements in uranium processes with respect to recovery of byproducts, process efficiency, economics and environment impact.

Work on this project was deferred for fiscal year 1987/88.

- **Project 30.61.02: Gold**
  Project leader : T. Cienski

Objective:

To develop new or improved processes to increase the recovery and reduce costs in the extraction of gold with special emphasis on refractory ores.

The main focus of the CANMET Gold Project is on the improved accessability to gold whose recovery is at present hindered by the type of ore, location of deposit or environmental regulations. These areas covered include investigations into alternatives to roasting, cyanidation and carbon adsorption. The principal emphasis was placed however on the refractory gold ores and on the search for technologies which would allow them to exploit ore efficiently. Ion-probe micro-analysis is being performed on a contract on various refractory gold ores. When completed, this analysis will provide additional information that will permit retention of best recovery strategy for a given type of refractory ore.

(a) Mineralogical investigations

An Unsolicited Proposal (23440-7-9037) was signed with Surface Science Western, University of Western Ontario on August 26, 1987 for delivery on August 31, 1988 and as amended in March, 1988. The title is "Ion probe microanalysis of gold in common sulphide minerals and implications for enhanced recovery from refractory gold ores". The UP involves ion probe microanalysis for gold, using a method developed with Surface Science Western (Chryssoulis, Cabri and Salter, 1987), of refractory ores from ten Canadian deposits and copper anodes from four copper refineries. The UP is funded by DSS bridge financing, CANMET, GSC and by ten mining companies whose ores are being examined. In spite of some delays due to instrumentation problems, the work is proceeding satisfactorily and it is anticipated that it will be completed on target. To end of March 1988, the copper anode analyses have been completed as well as analyses of sulphide minerals from two deposits. The gold distribution in the copper anodes has been confirmed to occur largely in the copper matrix and the gold contents, as determined by ion microprobe, correspond very closely to bulk assays. The analyses of refractory sulphide minerals, done to date, has not yet been assessed.

A paper on the mineralogy of gold ("La minéralogie de l'or") was prepared for presentation at the CANMET symposium in Val d'Or in February 1988.

(b) Northern placer testing laboratory

At the request of, and in cooperation with the Klondike Placer Miners Association, CANMET is involved, together with the University of British Columbia, in the installation of a fine-placer gold-recovery laboratory. Situated in Whitehorse the laboratory will treat tailings samples obtained from the placer operations and will evaluate economics and technologies of reducing fine gold losses. This project is in progress.

(c) Gold recovery from refractory concentrate

Pyritic-arsenopyrite refractory gold concentrate was calcined by microwave. To avoid formation of volatile As_2O_3 and SO_2 the concentrate was mixed with NaOH and the mixture was irradiated for 10-12 min with 6 kW microwave power. Almost all of the arsenic and sulphur were removed as water soluble species. The calcine was then leached with cyanide and gold and silver extractions were 99% and 70%, respectively. When acidic thiourea was used as lixiviant, the recoveries were 98% and 65%.

(d) Process improvement

At a Val d'Or area plant, a flotation concentrate yields 95% recovery with 150-160 h of cyanidization. In testwork at CANMET, a two hour pre-aeration reduced the leaching time to 24 h with a recovery as high as 98%.

(e) Resins

Both deep fluidized resin bed and the resin-in-pulp approaches were investigated for gold adsorption from solution. Although the results obtained did not demonstrate the superiority of resin ion exchange over activated carbon, more definitive work on a pilot circuit and on better resins is indicated to provide more meaningful evaluation of this technology.

(f) Solvent extraction of gold

Several organic reagents were evaluated for the purpose of the extraction of gold from clarified cyanide solutions. Because of their properties, quarternary amines appear to be the most suitable extractant for the solvent-in-pulp systems. The bench scale results were confirmed by running a continuous circuit of agitated columns. The mini pilot plant was run for 115 h treating 334 L of production plants leach solutions. The gold recoveries were 94-98% and gold concentrations in the organic up to 2.5 g/L.

(g) Solvent-in-pulp

Using the quaternary amine extractant identified for the solvent extraction of gold from cyanide solutions, initial pilot-plant trials have been carried out on gold extraction from a leach pulp. The equipment used was a version of the Graesser rotating bucket contactor modified to handle pulps with up to 50% solids. Surfactants were evaluated to help in settling the pulps and in minimizing the adsorption of organic onto the solids. A loading of 2 g Au/L was attained from a feed with 6 mg Au/L. However, solvent losses were excessive because of physical projection of the organic droplets into the pulp. Design modifications to the equipment are planned in order to overcome this problem. Testing will continue with the new design.

(h) Thiourea

The recovery of gold from thiourea solutions by hydrogen reduction has been studied. The process shows a good selectivity to precipitate gold and silver

in a solution containing impurities and no thiourea decomposition is reported. The precipitation can be performed at low pressure and at room temperature with high recoveries and good kinetics. The purity of the product obtained is comparable to the existing technology and the preliminary economical study shows that this approach is promising.

(i) Analytical development

A chromatographic system, based on ion-pairing chromatography using perchloric acid and UV detection, has been developed for the separation and detection of products from the oxidation of thiourea with hydrogen peroxide. This reaction can be followed by determining the thiourea, formamidine disulphide and sulphinic acid concentrations. Other products detected have not been identified.

• Project 30.61.04: Rare Earths
Project leader : R. Molnar

Objective:

In 1986 there were a number of inquiries from industries on the subject of extractive metallurgical processing of ores and byproduct recovery for the extraction of rare earth elements and other rare metals such as gallium. Considerable work had been carried out on the extraction of rare earths in the last 20 years but this work was never allocated its own project. Rather it had been carried out principally under the projects studying extraction of uranium and related byproducts.

Resources were therefore allocated to this project in 1987 to enable CANMET to carry out additional investigative work and share costs in support of cost recovery contracts which would arise from the inquiries. As it turned out, there were no inquiries in 1987 leading to any cost recovery work on rare metals. However, there is still genuine industrial interest in the subject and some work was carried out in anticipation of future demand for technology.

(a) Monazite flowsheet

A joint rare earth project with ANSTO was carried by an MSL scientist visiting Australia. Various feed sources and process options were surveyed. A monazite concentrate was selected as the feed ore. A hot caustic leach followed by hydrochloric acid dissolution of the caustic leach residue solubilized the rare earths and yttrium. Solvent extraction studies were carried out on the chloride solution. Several extractants were screened. An alkylphosphoric acid was selected. Equilibrium extraction and stripping data as well as stagewise scrubbing data were obtained. Some continuous mixer-settler tests were performed together with an initial test using a sieve-plate pulse column.

(b) Ion exchange recovery of gallium

The ability of an amidoxime resin to extract gallium from Bayer solutions has been demonstrated with bench-scale tests. Loadings of up to 4 g Ga/L of resin and 90% gallium recoveries were obtained. The loaded gallium can be eluted with mineral acid solutions or neutral solutions of EDTA or acetylacetone. Vanadium in the Bayer solution leads to a progressive decrease in resin capacity. This vanadium is not released during normal elution but is slowly removed by concentrated acid or alkaline treatment. However, the resin appears to be damaged by these harsh treatments. Current work is directed to finding a way to prevent the vanadium co-extraction or a method of effectively removing the vanadium from the resin.

Standards and Specifications

- **Project 30.69.01: Reference Materials**
  Project leader : C.W. Smith

Objective:

To support the reliability and quality of chemical and physical measurements of mineralogical and metallurgical materials of Canadian need and interest by the preparation and certification of minerals, ores, concentrates, metals, tailings and related materials for use as reference materials for composition.

In Canada, CANMET has accepted a lead role for the production and certification of mineralogical and metallurgical CRMs through the Canadian Certified Reference Materials Project (CCRMP). In this role, CCRMP has obtained the cooperation of a Canadian and international pool of measurement expertise to carry out its certification programs. The objectives and direction of CCRMP is reviewed by an Advisory Committee consisting of representatives from industrial, commercial and research institution laboratories involved with mineralogical and metallurgical measurements.

Current Status:

In the review period CCRMP sold some 1750 units of a variety of 67 different reference materials to produce a revenue of $146,000. This revenue has increased an average of 12% annually for the past five years. Seven reference materials for gold accounted for one third of the materials distributed reflecting the world-wide activity in exploration and deposit development for this resource.

In fiscal 1987, recommended values for eighteen constituents of copper concentrate reference material CCU-1a were established from measurements contributed by more than thirty participating laboratories. This material replaces CCU-1, third in popularity of CCRMP materials, which was depleted in later 1987.

Measurements by eighteen contributing laboratories established recommended values for sixteen constituents of uranium ore concentrate reference material CUP-2. Prepared with the cooperation of the Analytical Subcommittee of the Canadian Uranium Producers' Metallurgical Committee and Eldorado Nuclear Limited, CUP-2 provides a reference material for uranium and impurity constituents which are subject to evaluation in commercial transactions of this commodity.

Disk samples of zinc/aluminum alloys NZA-1 to NZA-7 were finished and stamped preparatory to their release as reference materials for three alloy and four impurity constituents. Prepared in cooperation with the Noranda Research Centre, their compositions are relevant to the ZA-8, ZA-12 and ZA-27 alloy series. Also to be available in chip sample form, release of these materials has been delayed pending completion of the project documentation.

Four ore tailings samples were prepared as candidate reference materials RTS-1 to RTS-4 from materials donated by Noranda Corporation, Inco and Falconbridge Limited. Intended primarily for quality assurance applications within the Reactive Acid Tailings Program (RATS), a measurement program for eighteen constituents was initiated with contributions from RATS participants and commercial laboratories.

Priority objectives for new reference materials for gold and platinum group elements at concentration levels of geochemical and exploration interest were endorsed by the Advisory Committee. Personnel of the Geological Survey of Canada will play a leading role in both acquisition of suitable materials and coordination of the measurement program for these materials. Suitable materials have been identified and collections are scheduled for this spring.

Staff of the Chemical Laboratory continued to provide critical information to establish composition and homogeneity of candidate reference materials and expert quantitative measurements for the certification projects. The Chemical Laboratory additionally participated in an interlaboratory study conducted by the Noranda Research Centre concerning the accuracy of trace element determinations in water samples. The instrumental techniques of atomic absorption and ICP atomic emission spectrometries were applied.

Staff members of the Extractive Metallurgy Laboratory continued to provide essential statistical expertise and computing support both for the assessment of measurement data and sales management of reference materials. They also carried out thermogravimetric measurements of RTS-1 to RTS-4 to assess the potential stability of these materials.

Facilities and staff of MSL were also involved in the preparation of fourteen candidate reference materials for private industry under cost-recovery arrangements with CANMET in fiscal 1987. The facilities were also used by Environment Canada staff to prepare a candidate smelter dust reference material.

A world-wide perspective on reference materials requirements is maintained through participation by MSL staff members in the Canadian Advisory Committee

on REMCO (Committee on Reference Materials of the International Organization for Standardization).

Contracts:

- Reqn. 23440-7-9166 (-01 to -11), "Chemical analyses of ore tailings reference materials", Various Canadian Commercial Laboratories. S.A.-C.W. Smith.

• **Project 30.69.02: Analytical Methodology**
Project leader : J.C. Hole

Objective:

To develop and improve analytical methods, techniques, and laboratory facilities, mainly in support of CANMET programs, and to participate in working groups and/or serve on committees of national and international organizations which develop and disseminate information on standard analytical methods.

1. Analytical Research and Method Development

(a) Determination of arsenic in ores, concentrates and related materials by hydride-generation atomic-absorption spectrometry

A recent graphite-furnace atomic-absorption method for the determination of about 0.2 μg/g or more of arsenic in ores, concentrates, rocks, soils and sediments, after separation by extraction as the xanthate from 8-10 M hydrochloric acid, has been modified to include an alternative hydride-generation atomic-absorption finish.

(b) Determination of selenium in ores, concentrates and related materials by graphite-furnace atomic-absorption spectrometry

A graphite-furnace method, involving the use of nickel as matrix modifier, has been developed for the determination of about 0.01 μg/g or more of selenium in ores, concentrates, rocks, soils and sediments after separation of selenium from matrix elements by toluene extraction of the 5-nitropiazselenol complex from about 4.2 M hydrochloric acid.

(c) Determination of antimony in ores, concentrates and related materials by graphite-furnace spectrometry

A graphite-furnace method, involving the use of palladium and thiourea as matrix modifiers, has been developed for the determination of about 0.1 μg/g or more of antimony in ores, concentrates, rocks, soils and sediments after separation of antimony from matrix elements by cyclohexane extraction as the xanthate from about 4.5 M hydrochloric acid.

(d) Determination of selenium and tellurium in ores, concentrates and related materials by hydride-generation atomic-absorption spectrometry

The determination of trace amounts of selenium and tellurium in ores and related materials by hydride generation atomic-absorption spectrometry, after their simultaneous separation by cyclohexane extraction as xanthates from about 10 M hydrochloric acid, is under investigation.

(e) Analysis of chromite concentrates

Suitable pretreatment and roasting procedures were developed for the fire-assay/atomic-absorption determination of gold and silver in chromite concentrates.

(f) Microwave decomposition techniques

The decomposition of ores and processing residues by microwave heating with acids in a pressurized vessel was investigated but showed no improvement in efficiency over conventional acid-decomposition techniques.

(g) Determination of trace elements in lead, zinc and copper concentrates by inductively-coupled plasma atomic-emission spectrometry after microwave-assisted sample leaching

An ICP-AES method, involving microwave heating of the sample for two minutes with aqua regia in a closed vessel, was developed for the determination of trace amounts of arsenic, antimony, bismuth, cadmium, tin and selenium in lead, zinc and copper concentrates.

(h) Determination of platinum, palladium and gold in solutions and solids

A classical fire-assay and conventional scorification procedure has been modified to allow the determination of platinum, palladium and gold in both solutions and solid samples by inductively-coupled plasma atomic-emission and atomic-absorption spectrometry.

(i) Application of UV spectrophotometric detection for high-performance liquid chromatography

UV spectrophotometric detection has been investigated for the determination of bromide, oxalate, nitrate and arsenic by HPLC.

(j) Determination of arsenic(III) and arsenic(V) by high-performance liquid chromatography/hydride-generation atomic-absorption spectrometry

A hydride-generation AAS method, involving the separation of the arsenic species by HPLC, has been developed for the determination of arsenic(III) and arsenic(V) in solutions.

(k) Determination of rare-earth elements in steels by dynamic ion-exchange chromatography

Dynamic ion-exchange chromatography has been applied directly to the determination of trace amounts (1 μg/g) of neodymium, praseodymium, lanthanum and cerium in steels after optimization of the effective capacity of the ion-exchanger coupled with the increased sensitivity of post-column detection with Arsenazo III.

(l) Determination of rare-earth elements in metallurgical materials by dynamic ion-exchange chromatography

By optimization of instrumental parameters, dynamic ion-exchange systems were developed for the determination of the rare-earth elements in zinc-aluminum alloys, in neodymium metal used for the production of super-magnetic alloys, and in various materials obtained during metallurgical processes such as the processing of rare-earth containing ores and the production of aluminum by the Bayer process.

(m) Fission-track technology

A "state-of-the-art" microscope and polishing apparatus were acquired during the review period and methodology was developed for mounting, polishing and etching zircon. Cost recovery work was successfully carried out on samples obtained from the University of Ottawa Geology Department, but not on samples from the Saskatchewan Research Council. In a joint program with the United States Geological Survey at Denver, two minerals, moldavite-tektite and obsidian-macusanite, which were chosen as candidate reference materials for fission-track age determinations, were analyzed numerous times to provide a relatively reliable age estimation.

(n) International Atomic Energy Agency laboratory manual

Chemical Laboratory staff are participating on a committee to prepare an IAEA laboratory manual on the analytical chemistry of the uranium exploration, mining and milling industry. Eight reports of methods to be included in this manual have been submitted and discussed. One additional report is in the final stages of preparation.

(o) X-ray fluorescence course at CANMET

A 3-day course on X-ray fluorescence analysis, held at 555 Booth Street, Ottawa, in May 1987, was co-sponsored by CANMET and the Analytical Subcommittee of the Canadian Uranium Producers Metallurgical Committee. It was given by two internationally-known resource people and attended by 22 people from industrial, government and other laboratories.

(p) Computerized LIMS system for the Chemical Laboratory

The microcomputer network linking each of the sections of the Chemical Laboratory was installed during the review period and the initial software has been completed and the system put into operation. Information on all samples

received by the Chemical Laboratory is now being entered into the system and analysis and monthly summary reports can be printed. Minor modifications to the software are being implemented as experience is gained with the system. The program to provide a Chemical Stores inventory system is about 95% complete.

(q) Internal reflectance and infrared spectroscopy

A cylindrical internal reflectance cell (CIRCLE CELL) was acquired and installed on the Digilab FTS-40 FTIR spectrometer. The equipment was tested using neutral solutions for the ZnSe crystal and acidic solutions having a pH of 2 for the AMTIR crystal. Concentrations between 2-30% of organic solutes gave acceptable spectra in the 3100-800 cm^{-1} range after spectral subtraction of the water solvent.

(r) Infrared examination of organic materials in hydrometallurgy

Methods were developed for examining some materials from hydrometallurgical processes. Regenerated reagent solutions from copper electrorefining, containing lignosulphonates and polypeptides in concentrated acid, and some fractions isolated from these solutions, were examined for degradation products and/or impurities. Limited supply of samples prevented concentration of these products for further study. Amidoxime ion exchange resins, which are being considered for use in recovery of gallium, were examined after gallium loading and after stripping with various acids.

2. Standards development

(a) ISO/TC 102 (iron ores)

Again this year, CANMET has made substantial contributions to this International Organization for Standardization Technical Committee.

(i) ISO/TC 102/SC 1 (sampling)

In addition to the continuing review of various standards relating to iron ore sampling, the subcommittee is also investigating the possible application of "variograms" for iron ore sampling. An MSL officer is representing Canada on the working group set up for this investigation.

(ii) ISO/TC 102/SC 2 (chemical analysis)

An MSL officer is Chairman of this sub-committee, and serves as Canadian corresponding partner for four of its working groups. Four interlaboratory studies of proposed analytical methods were completed, and numerous technical documents reviewed.

(iii) ISO/TC 102/SC 2/WG 12 (chemical analysis - working group on statistics)

An MSL officer serves as convener of this working group, which evaluates statistically all international tests conducted by the sub-committee. Six

sets of international tests were completed and evaluated. The results of these tests were instrumental in the acceptance, in principle, of these analytical methods as ISO standards.

(b) ISO/TC 183 (copper, lead and zinc ores and concentrates)

Two MSL officers are members of the Canadian Advisory Committee to this ISO Technical Committee. They are both members of the Hosting Committee for the ISO/TC 183 International Meeting to be held in Ottawa, May 1988.

(i) ISO/TC 183 (chemical analysis)

An MSL officer serves as Canadian corresponding partner for one working group, and has participated in three interlaboratory studies. Various technical documents have been reviewed.

(ii) ISO/TC 183/WG 10 (statistical evaluation)

An MSL officer serves as convener of this working group. Eight international tests at the standardization stage have been completed; the results are being evaluated statistically and will be reported to the international meeting of the technical committee to be held in May 1988.

(c) ISO/TC 69 (application of statistical methods)

This ISO Technical Committee is responsible for the development of generic standards on the application of statistical methods for use by other technical committees within ISO. An MSL officer serves as the Canadian representative to the working group on the revision of ISO 5725, a generic standard for the determination of accuracy of test methods. The same officer serves also as chairman of the Canadian Advisory Committee on sub-committees 3 and 6 as well as convener of SC 6/WG 4 on reference materials.

(d) International data collection and storage

MSL is the international centre for analytical data generated by both ISO/TC 102 and ISO/TC 183. The data bases, and also programs for retrieval and statistical evaluation of the data, are created and maintained by MSL personnel using the facilities of the EMR Computer Services Centre.

Reports:

- Barkley, D.J. and Dahms, T.E. "Dynamic ion exchange chromatography for the determination of rare earths in steels, alloys and advanced materials"; Division Report MSL 87-52 (OP).

- Barkley, D.J. and Dahms, T.E. "The analysis of rare earths in steels and Nd-alloy by dynamic ion exchange chromatography"; Division Report MSL 87-70 (J) (in press).

- Donaldson, E.M. and Leaver, M.E. "Determination of arsenic in ores, concentrates and related materials by continuous hydride-generation atomic-absorption spectrometry after separation by xanthate extraction"; Division Report MSL 87-114 (J) (in press).

- Donaldson, E.M. "Determination of selenium in ores, concentrates and related materials by graphite-furnace atomic-absorption spectrometry after separation by extraction of the 4-nitro-o-phenylenediamine complex"; Division Report MSL 87-139 (J) (in press).

- Cloutier, J.C. and Moloughney, P.E. "A rapid fire-assay/atomic absorption method for the determination of platinum, palladium and gold in ores and concentrates: A modification of the tin-collection scheme"; Division Report MSL 87-125 (OP&J) Draft.

- Sutarno, R. and Bowman, W.S. "ISO/TC 183/WG 6A - Determination of zinc in zinc concentrates: Statistical evaluation of international test data 1984-1986"; Division Report MSL 86-56 (IR).

- Sutarno, R. and Bowman, W.S. "ISO/TC 183/WG 5A - Determination of lead in lead concentrates: Statistical evaluation of international test data 1984-1986"; Division Report MSL 87-9 (IR).

- Sutarno, R. "ISO/TC 183 - Copper, lead and zinc ores and concentrates: Procedure for statistical evaluation of analytical data resulting from international tests"; Division Report MSL 87-18 (J).

- Sutarno, R. "ISO/TC 183 - Copper, lead and zinc ores and concentrates: Working Group operating procedure"; Division Report MSL 87-19 (J).

- Sutarno, R. "ISO/TC 69 - Canadian Delegation Report on ISO/TC 69/SC 6/WG 1 and WG 4 meeting held in London, U.K. 1987-05-18/21"; Division Report MSL 87-81 (TR).

- Sutarno, R. "ISO/TC 69 - Canadian Delegation Report on ISO/TC 69/SC 6, WG 1 and WG 4 meetings held in Atlanta, GA, U.S.A. 1987-09-14/18"; Division Report MSL 87-128 (TR).

- Sutarno, R. "ISO/DP 5725 Part 4 - Basic methods for estimating trueness of a test method"; Division Report 87-130 (J).

- Sutarno, R. "ISO/TC 183 - Copper and zinc ores and concentrates: Procedure for statistical evaluation of analytical data resulting from international tests (second draft)"; Division Report MSL 87-149 (J) Draft.

- **Project 30.69.03: Aggregate/Concrete Testing and Standards**
  Project leader : G.G. Carette

Objective:

To provide technical expertise and information for Canadian and international standards writing organizations concerned with aggregates and concrete, by performing development work on in-situ tests, NDT methods and other tests, by coordinating the CSA Sample Comparative Cement testing program, by organizing conferences on the use of NDT and new concrete materials and their durability, and by participating in committees of the CSA, ACI, ASTM, ISO, etc.

Aggregates, cement and concrete testing and standards contribute much to ensuring that concrete will perform as specified in construction projects, thus protecting public interest and safety.

(a) Joint comparative CSA Cement Sample Program

At the request of the Committee on Hydraulic Cements of CSA and the Canadian cement industry, a joint project was initiated at the end of 1978 between Canadian cement testing laboratories and CANMET to assess existing cement specifications and testing methods in Canada. CANMET is coordinating the program and is in charge of the overall organization, including the preparation and distribution of test samples and the compilation, analysis and publication of test data.

Also, at the request of the above committee, CANMET has initiated a new National Cement Reference Sample program for the purpose of providing the industry with a means of verifying their cement strength testing procedures. The reference sample was originally planned to be made available in the summer of 1987; however, because of need for additional characterization of the material, this has been delayed till 1988. The sample will be distributed through the Canadian Certified Reference Materials Project of CANMET.

(b) International workshop on condensed silica fume in concrete

CANMET sponsored a successful 2-day workshop on "Condensed Silica Fume in Concrete" in Montreal in May 1987. The purpose of the workshop was to provide the latest information on this new cementitious material and discuss its potential and limitations. The workshop included 22 technical presentations and was attended by 140 people from more than 12 countries.

(c) International workshop on slag in concrete

CANMET also sponsored a 2-day workshop on "Granulated Blast-Furnace Slag in Concrete" in Toronto in October 1987. A total of 23 technical presentations were made covering the latest developments related to the use of blast-furnace slag in concrete in various parts of the world. These included an update of CANMET work on the development of a new Canadian source of granulated blast-furnace slag for use in cementitious applications. The workshop was again a success, attracting 115 people from 9 countries.

(d) Seminar on fly ash

A seminar on the use of fly ash in concrete was held in Halifax in November 1987. This was the second seminar organized by CANMET for the purpose of providing the latest results of the research carried out under a Nova Scotia MDA on fly ashes. The seminar was well received with over 60 from the local engineering community attending.

(e) International conference on performance of concrete in marine environment

The second CANMET international conference on "Performance of Concrete in Marine Environment" is under preparation. The 5-day conference will be held in St. Andrews, N.B., in August 1988. The final program has been released and will include over 50 technical papers for presentation and publication in the conference proceedings.

Papers Published in Outside Journals:

- Carette, G.G. and Malhotra, V.M. "Characterization of Canadian fly ashes and their relative performance in concrete"; Canadian Journal of Civil Engineering 14:667-682; 1987.

Papers Published in Conference Proceedings:

- Malhotra, V.M., Carette, G.G. and Bremner, T.W. "Durability of concrete containing supplementary cementing materials in marine environment"; Proceedings of the Katharine and Bryant Mather International Conference on Concrete Durability; Atlanta, Georgia; 1987.

- Sivasunderam, V., Carette, G.G. and Malhotra, V.M. "Superplasticized high-volume fly ash system to reduce temperature rise in mass concrete"; Proceedings of the Eight International Ash Utilization Symposium; Washington, D.C.; 1987.

Presentations:

- Carette, G.G. "Preliminary data on long-term strength development of condensed silica fume concrete"; International Workshop on Condensed Silica Fume in Concrete; Montreal, Quebec; May 1987.

- Carette, G.G. "Superplasticized high-volume fly ash system to reduce temperature rise in mass concrete"; Eight International Ash Utilization Symposium; Washington, D.C.; October 1987.

Miscellaneous:

- Member of Organizing Committee; International Workshop on Condensed Silica Fume in Concrete; Montreal; 1987.

- Member of Organizing Committee; International Workshop on Granulated Blast-Furnace Slag in Concrete; Toronto; 1987.

Byproduct Recovery

- **Project 30.77.01: Silver Recovery in the Zinc Industry**
  Project leader : J.E. Dutrizac

Objective:

To increase the recovery of silver in Canadian zinc plants to >75%. This will be achieved by elucidating the behaviour of silver in conventional and proposed zinc circuits and by determining the chemical and mineralogical balances of silver in these operations. An equally important objective will be to develop at the bench and mini plant scales, new processing technology to increase silver recoveries in zinc plants by 1987. The success of the project will be measured in terms of scientific reports and of new processing concepts to increase silver recoveries.

Canada is the world's largest supplier of zinc concentrates and is also a major producer of zinc metal. Although all Canadian commercial zinc concentrates contain potentially recoverable quantities of silver, current silver recoveries in some Canadian plants are negligible. Thus, there is a genuine need for a thorough examination of the whole problem of silver deportment and recovery in the zinc industry - commencing with the ore and proceeding through the various processing steps to the final products and/or residues.

(a) Successful project completion

This project, which has been developed in close co-operation with the Canadian zinc industry, terminates at the end of the 1987/88 fiscal year. All project objectives have been satisfied. Via CANMET contracts with Noranda Research Centre, a flotation process was developed that is capable of recovering >75% of the silver in zinc neutral leach residues into a ~1% Ag concentrate. Furthermore, a significant amount of work has characterized the mineralogical deportment of silver during zinc processing, and also has offered considerable insight into the associated iron control problem. New sensitive methods of silver analysis were developed, and the effects of silver recovery processes on subsequent zinc electrolysis were elucidated. The successful completion of this project should facilitate silver recovery in those Canadian zinc plants which currently recover no precious metal byproducts.

(b) Mineralogical investigations

Several zinc leach residues and flotation concentrates made from the residues have been examined mineralogically to elucidate the forms of silver present. In flotation concentrates made from neutral leach residues silver is present mostly in sulphide form, commonly as Ag_2S rims on sphalerite or as tiny Ag_2S grains in elemental sulphur-silica gel spheroids. By contrast, the silver in concentrates made from super hot acid leach residue occurs mostly as AgCl, and the AgCl grains commonly are occluded in elemental sulphur-silica gel.

(c) Silver in zinc processing

Silver can be leached from zinc residues by thiourea, and commercial interest currently is being shown in this process. The fundamental aspects of the reaction of thiourea with silver metal have been studied and a report has been issued.

Silver often is present in zinc residues as jarosite-type compounds from which silver cannot be readily leached. Studies were done to examine the decomposition of jarosite-type compounds at ~225°C to form environmentally stable Fe_2O_3 and to liberate the silver. Some success has been achieved, and it seems that the silver collects on residual sphalerite which likely can be recovered by flotation from the hematite product.

(d) Zinc electrowinning

As part of a continuous project to optimize zinc electrowinning from acid sulphate electrolyte, a paper describing the characteristic effects of 15 impurities and their interaction with glue under commercial electrowinning conditions was published.

Efforts to recover silver from zinc leach residues have focussed on flotation and thiourea leaching. Solvent extraction processes also are being examined for iron control in zinc circuits. Because the possibility of organic contamination of zinc electrolytes exists, the effects of thiourea, flotation reagents and some organic extractants on the current efficiency, polarization behaviour and deposit morphology-orientation have been studied. All organics are detrimental, but the organics can be partly controlled by activated carbon treatment.

Contracts:

- Reqn. 4-9295, "Computation of PIXE analytical data', University of Guelph. S.A. - L.J. Cabri.

- Reqn. 5-9054, "Recovery of silver from zinc plant residues - Phase II", Noranda Research Centre. S.A. - J.E. Dutrizac.

- Reqn. 5-9129 MDA, "Gold-silver recovery from zinc pressure leach residues-Phase I", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

- Reqn. 5-9220 MDA, "Metal recovery oxide residues", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

- Reqn. 6-9191 MDA, "Gold-silver recovery from zinc pressure leach residues-Phase III", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

Reports:

- Dutrizac, J.E. and Chen, T.T. "Mineralogical characterization of silver flotation concentrates made from zinc leach residues"; Division Report MSL 88-21 (J) Draft.

- Dutrizac, J.E. "An overview of iron precipitation in hydrometallurgy"; Division Report MSL 87-43 (J).

- MacKinnon, D.J., Dutrizac, J.E., Brannen, J.M. and Hardy, D.J. "The behaviour of thiourea and flotation reagents in zinc electrowinning circuits"; Division Report MSL 87-65 (J).

- Chen, T.T. and Dutrizac, J.E. "Mineralogical characterization of two alunite and two natrojarosite samples"; Division Report MSL 87-75 (TR).

- Dutrizac, J.E. and Chen, T.T. "Mineralogical characterization of the silver flotation concentrate made at Vieille-Montagne, Balen, Belgium"; Division Report MSL 87-99 (J) Draft.

- Chen, T.T. and Dutrizac, J.E. "Mineralogical characterization of silver flotation concentrates made from zinc neutral leach residues"; Division Report MSL 87-118 (J) Draft.

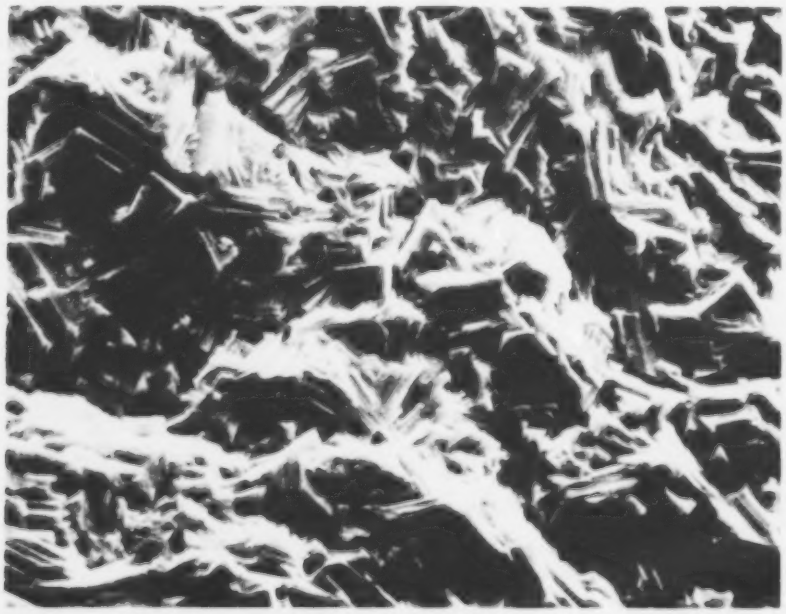

Fig. 4. SEM micrograph showing the structure of a good commercial zinc deposit

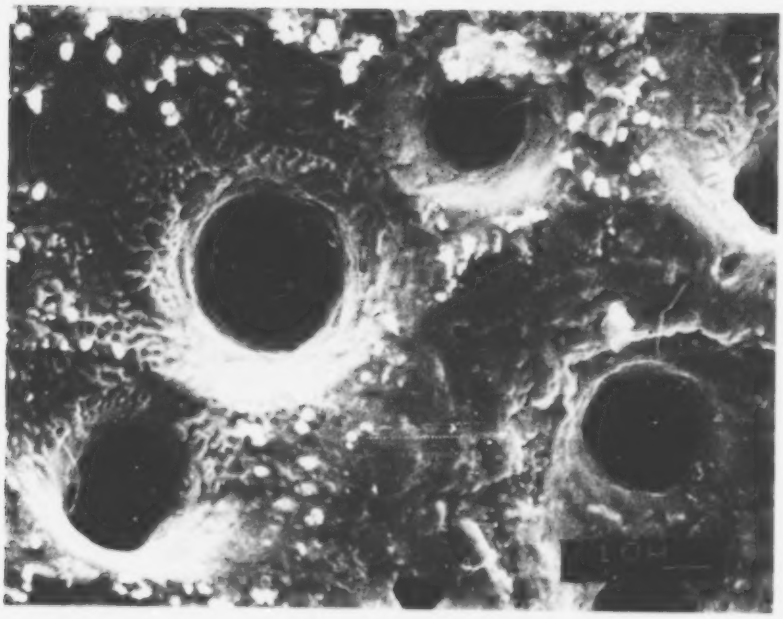

Fig. 5. SEM micrograph showing the detrimental effect of solvent extraction reagents on the zinc deposit morphology even after activated carbon treatment. The circular holes are likely sites of unwanted hydrogen gas evolution

- **Project 30.77.02: Non-Ferrous Metallurgical Slags**
  Project leader : A.H. Webster

Objective:

To develop methodology to reduce the loss of valuable metals such as nickel, copper, cobalt and precious metals and to increase the rejection of undesirable elements such as arsenic, bismuth and antimony into slags through better understanding of the factors affecting metal losses to slags, and to recommend practices for control.

Most concentrates of copper, nickel and lead sulphide ores are treated by pyrometallurgical smelting. Many of the concentrates sent for smelting contain minor amounts of valuable metals, for example, cobalt, precious metals, molybdenum and zinc, some of which may be lost to the slag. Methods for decreasing these losses or for recovering the metals from the slag before it is discarded would help conserve Canadian mineral resources by increasing recoveries from the ores.

(a) Extraction of valuable metals from slag into high-iron matte

An investigation of recycling of iron sulphide matte with fresh molten slag in order to increase the concentrations of Ni, Co and Cu in the matte was completed and the report is underway.

The treatment of industrial slags with high-iron matte (pyrrhotite) in order to retrieve valuable elements like nickel, cobalt and copper was found promising. These elements were found to collect in two distinct phases in the cooled sulphur-deficient matte; an iron-rich phase containing most of the nickel and the cobalt, and a bornite-like phase containing most of the copper. To enhance the extraction process, additions of carbon and of iron were implemented to provide a more reducing environment, particularly needed for the extraction of cobalt. These series of experiments were done under previously optimized conditions using a slag/matte ratio of 6/1 at 1250°C in an oxygen-free argon atmosphere. Chemical analysis and electron microprobe analysis were used in the study.

In the preliminary stages of the study, the effects of the addition of carbon on the slag and on the pyrrhotite separately were examined. Optimization of experimental parameters like sample geometry, type and particle size of carbon and crucible material was done. Carbon additions of 1, 3, 5 and 10 mass% (relative to the slag) were implemented. The results indicated that, with more carbon added, and hence stronger reducing environment, substantially better extraction of nickel, cobalt and copper was attained. Separation of the matte from the slag, however, was found difficult, particularly with higher carbon addition. Optimum extraction of the three elements was found to occur at 3-5% carbon addition.

Similarly, the effect of iron additions of 1, 3, 5 and 10 mass% to the slag/matte mixtures were examined. The results indicated that the addition of iron improves the extraction of nickel, cobalt and copper from the slag to the matte although not up to the levels achieved with carbon. The copper extraction was the least influenced by the addition. Metallic iron in the cooled matte acted as a collector to form an iron-rich alloy with most of the nickel and the cobalt; a bornite-like phase contained some of the copper. The optimum addition of iron was found to be 3-5%. The recovery of the matte from the slag after the treatment was found much easier than in the case of carbon addition.

Investigation of methods for concentrating nickel, cobalt and copper (in a recoverable form) extracted into the FeS matte has commenced.

(b) Cobalt distribution between slag and high-iron matte

Laboratory experimental studies were carried out on the equilibrium distribution of cobalt between molten slag and FeS matte. The influence of various experimental parameters such as the method of sampling, the amount and form

of added cobalt, the length of time the melt is kept at the desired temperature and the presence, or absence, of nickel and copper was examined. Preliminary results indicated that the distribution coefficient of cobalt may be dependent on the amount of cobalt added in the molten mixture.

(c) Industrial liaison

A shared-cost contract with Falconbridge Limited to conduct experimental investigations to provide information for the development of an improved clean smelting process has been completed. The results of the four-part investigation should lead to improvements in the Falconbridge process that will decrease SO_2 emissions and improve nickel and cobalt recoveries while maintaining reliable furnace operation.

Contracts:

- Reqn. 3-9172, "To develop a clean smelting process for highly roasted copper-nickel calcines and to improve metal recovery", Falconbridge Ltd. S.A. - A.H. Webster.

Environmental Controls

- **Project 30.86.01: Tailings Characterization and Control Mechanisms**
  Project leader : G.M. Ritcey

Objective:

To contribute to the development of methodology for the effective control and disposal of potential environmental contaminants discharged from mine/mill operations.

It is becoming increasingly evident that the existing methods for the containment and disposal of mine-mill wastes are not without environmental difficulties related to acid generation and the release of many other potentially noxious elements.

The most desirable approaches to resolving these problems are those which employ well-known unit processes which can be readily substituted for those presently in use, or added on to existing processes.

CANMET's role will include contributions to the development of new processing steps for the removal of pollutants in mills prior to discharge, the development of methods for the treatment of effluents and the development of methods for containment technology.

In order to obtain the required understanding necessary to solve the tailings problem, the emphasis is on the biogeochemical interaction occurring in tailings and their affecting migration. Therefore, considerable emphasis is placed on controlled weathering tests in lysimeters.

Lysimeters

Lysimeters continued to be the major test procedure in the examination of tailings. The various areas of research are noted below:

(i) Tests of bog covers over tailings of different compositions are almost completed. The lysimeter tests are now completed with the exception of two tailings which did not respond to the cover. These tailings did not provide an effluent with an accepable pH. The remaining three have been continued with increased depth, with seemingly the desired results.

Several different types of bog cover have been examined, indicating a response from within a couple of years up to 10-12 years depending upon the type of bog. These lysimeters will be completed within a few months.

(ii) Simulated deep lake disposal tests have continued with very little change over the past year. Another year of simulated weathering should indicate whether the Noranda pyrite test (92%) is oxidizing. The pH of the effluent is 4, while that of the lower grade sulphide of Elliot Lake (2%) remains at about neutral.

(iii) As part of predictive technology of acid mine drainage (AMD) from waste rock and tailings, several lysimeters were set up to obtain data from simulated weathering tests. The tests are conducted on waste rock and tailings. The waste rock originates from Equity Silver, Curragh, Inco and Heath Steele, while the tailings are from Heath Steele, Curragh, Equity Silver, Waite Amulet, Elliot Lake, Key Lake, Noranda Bell and Westmin.

The tailings from Heath Steele, Inco and Waite Amulet went acid immediately. The waste rock is slower, with Heath Steele now becoming acid and the other gradually decreasing in effluent pH value.

(iv) Solbec tailings tests are being examined to determine the rate and completeness of extraction. Because they were becoming acid immediately, the tailings were washed with lime (to remove oxidized salts). Subsequent measurements of the pH indicates a neutral pH. Any decrease on pH in the future will then be indications of oxidation occurring.

(v) Samples of manganese ore from N.B. are being leached with acid generated from oxidation of Heath Steele tailings. The tests have only been in progress for about ten weeks, but the leaching is gradually increasing to 1 g/L Mn at pH 6 and Eh 300 mV.

CANMET-Industry Interface

Numerous contacts and requests were made from industry pertaining to problems being encountered in tailings sites. Generally the requests were for assessment of their problems, in many cases acid generation; advice on covers, or advice on treating contaminated seepage solution.

Seminars were presented to industry in Saskatchewan and Vancouver on the initial results of the use of geopolymers for potential application to the mining industry. A total of about 60 persons attended.

A two-day seminar on CANMET tailings activities was organized and held at CANMET in September. Approximately 75 attended from industry.

- **Project 30.86.02: Mine/Mill Waste Management**
  Project leader : N. Davé (MRL)

Background:

The environmental problems associated with managing mine/mill waste containing metal sulphides are well recognized. Upon weathering, many metal sulphides, such as pyrite, marcasite and pyrrhotite in tailings oxidize in the presence of moisture, oxygen and iron-oxidizing bacteria - thiobacilli ferrooxidans. The oxidation produces acidic conditions within the tailings which subsequently leach many residual metals (and trace radionuclides in uranium tailings) from the tailings material resulting in highly acidic, high total dissolved solids, tailings porewater. With precipitation and recharge events, these oxidation reaction products can migrate from the tailings with surface run-off and as subsurface seepage to the surrounding environment, thereby affecting the natural quality of the area water system if control methods were not used. To control wind and water erosion, many inactive tailings sites have been successfully stabilized by revegetation which has greatly improved the aesthetics, and to a certain extent, the amount of water percolating through, because of increased evapotranspiration. The overall impact of revegetation on quality and quantity of effluent from reclaimed tailings areas has yet to be determined. Other tailings management options such as dry and wet covers, in situ consolidation of tailings and down stream passive treatment are to be evaluated for their long-term physical and chemical stability and effectiveness in minimizing acid generation potential.

Objective:

The objective is to develop an effective technology of tailings disposal and management which will enable the mining industry to abandon mine/mill waste in a predictable, cost effective and environmentally acceptable manner.

Achievements:

Under the Reactive Acid Tailings (RATS) program, hydrogeochemical investigations of a reactive sulphide tailings basin are being carried out at the

Waite Amulet tailings site in Noranda, Quebec. The study included measurements of solid phase physical, chemical and mineralogical parameters, liquid phase porewater geochemistry of unsaturated and saturated zones, and unsaturated zone pore-gas composition.

The results showed that the unsaturated zone porewater had a pH generally less than 3 with elevated metal levels. Pyrrhotite and pyrite were strongly oxidized in the near-surface zone and exhibited decreases to negligible alteration with depth. The saturated zone water has a pH generally greater than 5 with significantly lower dissolved metal levels. The mineralogy in the saturated zone indicated minimal to no signs of pyrrhotite and pyrite alteration.

The pore gas oxygen concentrations in the unsaturated zone indicated that O_2 was present generally to depths less than 1 m. This is consistent with the oxidation profile, and gaseous O_2 availability may control oxidation.

Consolidation and strength characteristics of pyritic uranium tailings stabilized with lime, carbon dioxide and blast furnace slag cement were measured for backfill and in situ consolidation applications. The ultimate compressive strengths for tailings/lime stabilization were comparable to that of tailings/cement with no noticeable effect of the carbon dioxide mixing environment. The highest compressive strength and modulus of elasticity were obtained for blast furnace slag cement where the presence of aluminum oxide and silica provided additional binding and strength with the formation of hydrated alumino silicates.

The geochemistry of a thickened tailings pile at the Denison tailings site in Elliot Lake was evaluated to determine its chemical stability. The results have shown that the pile has been completely oxidized with the unsaturated zone pH ranging between 2-3 with elevated metal and sulphate levels.

The revegetation potential of a previously reclaimed and flood damaged section of the Nordic tailings site in Elliot Lake was evaluated for the established volunteer vegetation growth. About 50% of the damaged area has a vegetation cover with a bio-yield of 30% compared to that of the undamaged vegetated section.

Future Work:

Collaborative work between the Elliot Lake Laboratory and participating RATS member companies such as Noranda, INCO, Falconbridge and Cominco will be continued. Major areas of future research will be in the direction of predictive modelling and cover technology.

With the cooperation of Denison and Rio Algom Mines in Elliot Lake, studies on the thickened tailings pile and future close-out options will be continued.

In cooperation with Laurentian University, Sudbury, migration of radionuclides from uranium tailings via various environmental pathways will also be pursued.

Papers Published and Reports:

- Siwik, R. and Davé, N.K. "Hydrogeochemical investigations of the reactive tailings at the Waite Amulet Tailings site, Noranda, Quebec"; Proc. 19th Annual Meeting of Canadian Mineral Processors Operators Conf. 330-354; January 1987.

- Clulow, F.V., Davé, N.K., Lim, T.P. and Cloutier, N.R. "Uptake of Ra-226 by established vegetation and black cut worm larvae (Agrotis Ipsilon, Leipdoptera: Noctuidae) on uranium mill tailings at Elliot Lake, Ontario, Canada"; Accepted for publication in Health Physics; 1987.

- Davé, N.K. and Lim, T.P. "Effects of various tailings covers on radon gas emanation from pyritic uranium tailings"; Proc. 1987 Symp. on Mining, Hydrology, Sedimentology and Reclamation 99-104; Division Report MRL 87-84; University of Kentucky; Lexington, Kentucky; December 1987.

- Davé, N.K. "Tailings research at the Elliot Lake Laboratory, CANMET, EMR"; Presented to Tailings Seminar, and to be published in Proc.; Ottawa; 1987 (Report in progress).

- Lim, T.P., Davé, N.K. and Cloutier, N.R. "High resolution alpha-spectrometric technique for radium isotope analysis: The effects of sample thickness and filter pore size"; Submitted for publication to Int. J. Applied Radiation and Isotopes; Division Report MRL 87-12; 1987.

- Davé, N.K., Lim, T.P. and Chakravatti, J.L. "Consolidation strength characteristics of pyritic uranium tailings using: (1) powdered and hydrated lime in a carbon dioxide environment: (2) slag cement"; Division Report MRL 87-93; 1987.

- Davé, N.K. and Lim, T.P. "Radiological survey at the Belledune fertilizer plant, Belledune, N.B."; Division Report MRL 87-166 (CF); 1987.

- **Project 30.86.03: Water Pollution Control**
  Project leader : B.H. Lucas

Objective:

To establish technology for the control of water pollution to meet the standards set by regulatory agencies for the mining and processing of minerals by identifying potential problems and examining methods for the removal of environmental contaminants from metallurgical processes liquid waste streams.

The Mineral Sciences Laboratories have had an interest for many years in the treatment of liquid effluents from the mining industry. These include heavy metals, cyanide, arsenic and thiosalts. Priority will be given to the removal and containments of sludges from the treatment processes to clean up

liquid effluents of arsenate, thiosalts, cyanide, heavy metals and other undesirable contaminants.

(a) Impurity behaviour during iron precipitation

Hydrometallurgical processing solutions often contain modest concentrations of As and P, and it is possible to control these impurities, at least in part, during iron precipitation. It was shown that dissolved phosphorus was precipitated as the ferric analogue of giniite ($Fe^{2+}Fe_4^{3+}(PO_4)_4(OH)_2(H_2O)_2$) when phosphate-bearing solutions were heated to ~200 °C in the presence of excess iron. The products vary somewhat in iron content, and poorly crystallized phases are formed at temperatures <150 °C. The precipitation reaction is insensitive to pH values in the range 0.6-1.4, but amorphous gels are formed at pH >2. Finally, it was shown that the synthetic giniite did not incorporate significant amounts of magnesium, but that ~3 wt % SO_4 could be substituted in the synthetic giniite structure.

(b) Analytical development

(i) Determination of anionic species in samples from the AVR cyanide recovery process by high-performance liquid chromatography

Work on an HPLC method, which involves reversed phases coated with a "permanently" sorbed ion-exchanger coupled with indirect UV detection, for the determination of chloride, cyanate, sulphate, thiosulphate, thiocyanate and dithionate in samples from AVR cyanide recovery processes has continued during the review period. By optimization of instrumental and other parameters good resolution and a low detection limit (~0.05 μg/mL) have been obtained for the early eluting anions and for the more strongly retained sulphur species. The separation time for these anions is about 8 min.

(c) Cyanide and metal recovery from gold mill barren solutions

R&D has proceeded to where application of the technology to both current gold mill flowsheets and to flowsheets for developing operations is encouraged.

CANMET is able to carry out feasibility tests utilizing about 200 L of solution. Any interested party is invited to enquire about a negotiated fee which would be based upon cost recovery principles. Placer-Dome Inc. is currently a client.

The process is unsophisticated and hazard-limited. A stagewise control of key steps enables it to be an attractive alternative to destruction methods.

Acidification/Volatization/Reneutralization (AVR) objectives are:

1. Maximization of barren recycle volume and its cyanide content, as well as metal rejection.
2. Minimization of the volume bled to the environment (<3%) as well as its impact upon the environment (negligible cyanide and metal content).

3. Metal containment (75%-99%) in a low quantity precipitate which is readily isolated for recovery of valuables (metal, cyanide).
4. No addition, or formation, of undesirable components.

Continuous development of supportive technology is planned and underway (ion exchanger utilization, reverse osmosis, precipitate rectification).

(d) Radium adsorption

Lysimeter effluent is currently still being fed to the contactor containing fluidized, finely-ground barite. The total throughput is now 4.7 tonnes averaging ~100 pCi Ra^{226} per litre. The output remains at <10 pCi/L and therefore the estimated radium loading on the barite is >7500 pCi/g. The residence time in the mechanically stirred unit remains at 5½ h.

Reports:

- Dutrizac, J.E. and Jambor, J.L. "The synthesis of crystallized scorodite, $FeAsO_4.2HO$"; Division Report MSL 87-39 (J).

- Jambor, J.L. and Dutrizac, J.E. "Synthesis of ferric analog of the ferrous-ferric phosphate, giniite"; Division Report MSL 87-14 (J) Draft.

- McNamara, V.M. and Ritcey, G.M. "Cyanide abatement process for gold mill effluent treatment"; Division Report MSL 88-3 (OP&J) Draft.

Contracts:

- Reqn. 7-9212, "Survey of means to minimize and/or utilize mill effluent sludges", Gionet, Mellor, Leibich Assoc. Ltd. S.A. - B.H. Lucas.

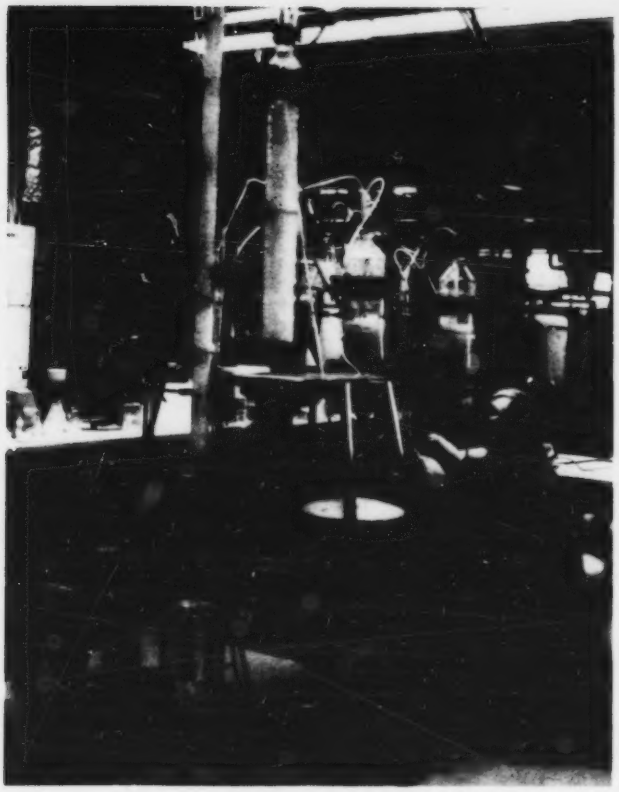

Fig. 6. Photograph of AVR process for cyanide recovery

- **Project 30.86.04: Air Pollution Control**
  Project leader : J.M. Skeaff

Objective:

To evaluate and where feasible to develop effective and acceptable methods for the monitoring and control of noxious elements encountered in Canadian pyrometallurgical processes. Investigations will focus on developing thermal data presently lacking for arsenides and arsenates, as well as methods for eliminating SO_2 in smelter off-gases.

The emissions of noxious elements and their compounds during pyrometallurgical processing of Canadian ores and concentrates is an area of concern to federal and provincial health and environmental protection organizations as well as to private industry. Of particular concern are non-ferrous roasting and smelting operations which result in SO_2 emissions as well as the emission of arsenic and mercury, and in many cases small quantities of other toxic

elements such as cadmium, selenium, tellurium and lead. A need exists for more definitive data on the disposition of these trace elements in concentrates and process streams, and on modifying flowsheets or developing pollution abatement equipment for the economic removal and disposal or recovery of these elements, in particular those associated with dusts from smelters which, due to economic or location factors, do not have an acid plant and thus constitute particular problems as do the roasting operations associated with the recovery of gold, silver, nickel and cobalt from arsenical ores.

(a) Thermochemical studies of arsenides and arsenates

Thermochemical and DTA studies are being conducted to determine the thermal properties of arsenides and arsenates (those of Ni, Fe, Co, Ag, Zn and Ca) at elevated temperatures to develop data which will enable the prediction of the behaviour of arsenic-bearing systems in pyrometallurgical processes, e.g., roasting, smelting, refining, etc.

An investigation of the thermochemical properties of certain arsenates and arsenides is being conducted by an equilibrium electrochemical technique in which a partially stabilized ZrO_2-CaO electrolyte is employed in an oxygen concentration cell to measure galvanic potentials. To date, thermochemical data for the nickel arsenides and $FeAsO_4$ as well as preliminary data for Ag_3AsO_4 and $Ni_3As_2O_8$ have been obtained. The resulting data can be used to predict stable condensed phases and gas compositions occurring under roasting or other pyrometallurgical conditions.

Work has been initiated to determine the thermochemical properties of metallic arsenides by a novel electrochemical cell design in which pellets of two metallic arsenides and calcium arsenide are compressed on either side of a single crystal of calcium fluoride electrolyte. Oxygen must be rigidly excluded from the cell compartment. Preliminary results indicate that the cell exhibits reversibility with respect to temperature. If successful, the cell design should enable the determination of the decomposition pressures and thermochemical properties of metal pnictides such as the arsenides as well as metal chalcogenides. The resulting data can be used to predict stable condensed phases and gas compositions occurring under roasting or other pyrometallurgical conditions.

A study of the oxidation and thermal dissociation of skutterudite [$(Co,Fe,Ni)As_3$] by differential thermal analysis and thermogravimetry is being completed. The results indicate that the course of oxidation is dependent on sample geometry, skutterudite particle size, heating rate and oxygen partial pressure. The course of oxidation appears to be governed by the ease of egress of volatilized arsenic which results from the thermal decomposition of cobalt arsenides. During thermal dissociation, there is a gradual release of arsenic vapour accompanied by the formation of mono- and di-arsenides. The oxidation product is a complex mixture of arsenides and arsenates. There is no evidence of the formation of any cobalt oxide species. The resulting data can be used to predict the behaviour of skutterudite under roasting or other pyrometallurgical conditions.

A thermal analysis study was conducted by thermogravimetry to determine the behaviour of $CoAs_2$ and $CoAs_3$ when heated in an inert atmosphere. The results indicate that $CoAs_2$ starts to decompose around 550°C and that decomposition terminates around 900°C depending on the rate of heating. The final products are solid CoAs and arsenic vapour. The decomposition of $CoAs_3$ was found to take place in the temperature range 520-750°C, and, as with $CoAs_2$, also depended on the rate of heating. The final products were solid $CoAs_2$ and arsenic vapour with the former decomposing further to CoAs and arsenic vapour.

Publication:

Wilson, L.J. and Mikhail, S.A. "Investigation of the oxidation of niccolite by thermal analysis"; Thermochimica Acta 112; 197-213; 1987.

Contracts:

- Reqn. 6-9066, "Development of a solid state sulphur probe for use in pyrometallurgical processes (UP-M584)", J. Kirchnerova and C.W. Bale, Ecole Polytechnique, Montréal. S.A. - J.M. Skeaff.

Patent Application:

- United States Patent Application No. 052,027, "A solid state arsenic probe for use in pyrometallurgical processes"; Kirchnerova, J., Skeaff, J.M. and Bale, C.W.

Report:

- Skeaff, J.M. "Thermochemical arsenate-oxide equilibria in the system Fe-As-O determined electrochemically between 317° and 536°C"; Division Report MSL 88-2 (J) Draft.

- **Project 30.86.06: Secretariat, Reactive Tailings Study (RATS)**
  Project leader : E.G. Joe

Objective:

To provide a comprehensive scientific, technical and economical basis for the mining industry and governmental agencies to predict, with confidence, the long-term management requirements for reactive tailings and waste rock.

To establish techniques that will enable the operation and abandonment of acid-generating tailings and waste rock disposal areas in a predictable, affordable, timely and environmentally acceptable manner.

The Technical Working Group of RATS has recommended a comprehensive national program of research for the mining industry and the provincial and federal governments.

The eight major research areas in the program:

- State of the Art;
- New Disposal Methods;
- Evaluation of National Uranium Tailings Program Information (NUTP);
- Research Procedures;
- Predictive Techniques;
- Passive Barriers;
- Waste Rock Rehabilitation

have been organized into five main sectors containing thirty-eight projects at a cost estimate of $12.5 million.

A summary of the RATS projects is as follows:

1.	Prediction Techniques	$ 3 765 000
2.	Prevention and Control	$ 5 705 000
3.	Treatment	$ 1 285 000
4.	Monitoring	$ 385 000
5.	Technology Transfer	$ 225 000
	Contingency	$ 1 135 000
	Total Program	**$12 500 000**

CANMET has printed several hundred copies of the RATS program for distribution to the mining industry, federal and provincial agencies, research centres and universities. Further additions of amendments to the program will depend on comments and suggestions from the recipients of the report.

A new organization to fund, manage and implement the program is being planned by EMR (CANMET), the Mining Association of Canada (MAC) and by the provincial departments responsible for mine waste management and regulation.

Fluidized-Bed Combustion

- **Project 50.62.01: Bubbling Bed Performance Parameters**
  Project leader : F.D. Friedrich (ERL)

Objectives:

To delineate parameters influencing the performance of Canadian coals and other solid fuels, and pitch residues from oil sands/heavy oil upgrading; to characterize the sulphur sorbent performance of Canadian limestones, and study the effects of fuel ash on sorbent performance; to advance the level of knowledge concerning fundamental mechanisms of FBC.

(a) Characterization of the sulphur sorbent performance of Canadian limestones

Fluidized bed combustion is an environmentally benign technology for the utilization of high-sulphur coals wherein limestone is added to the combustion chamber to capture sulphur dioxide. MSL's portion of this project, which was to characterize Canadian limestones as SO_2 sorbents, was completed this year. The bench-scale fluidized bed reactor, used to evaluate limestones, will be maintained to service future industry and power companies' requirements. The past five years' work on the evaluation of SO_2 sorbents has been compiled as a CANMET Report. The FBR was recently used to evaluate coke-oil-limestone agglomerates prepared by the Division of Chemistry of NRC.

(b) Characterization of reaction products from fluidized bed combustion

A comprehensive thermal analysis method using thermogravimetry was developed for the quantitative determination of the major reaction products in fluidized bed combustion ash. The ash components of interest, calcium sulphate and calcium carbonate as well as uncombusted carbon, are in a complex mixture and are difficult to analyze accurately by conventional chemical methods. X-ray diffraction and scanning electron microscopy were used as supplementary techniques for the verification of thermal analysis results.

Reports:

- Hamer, C.A. "Evaluation of SO_2 sorbent utilization in fluidized beds"; CANMET Report CM 86-9E.

- Hamer, C.A. "Evaluation of SO_2 sorbent utilization in fluidized beds"; Division Report MSL 87-10 (OP&J).

- Mikhail, S.A. "Thermogravimetric method for the determination of major reaction products in fluidized-bed coal combustion processes"; Division Report MSL 87-80 (OP&J).

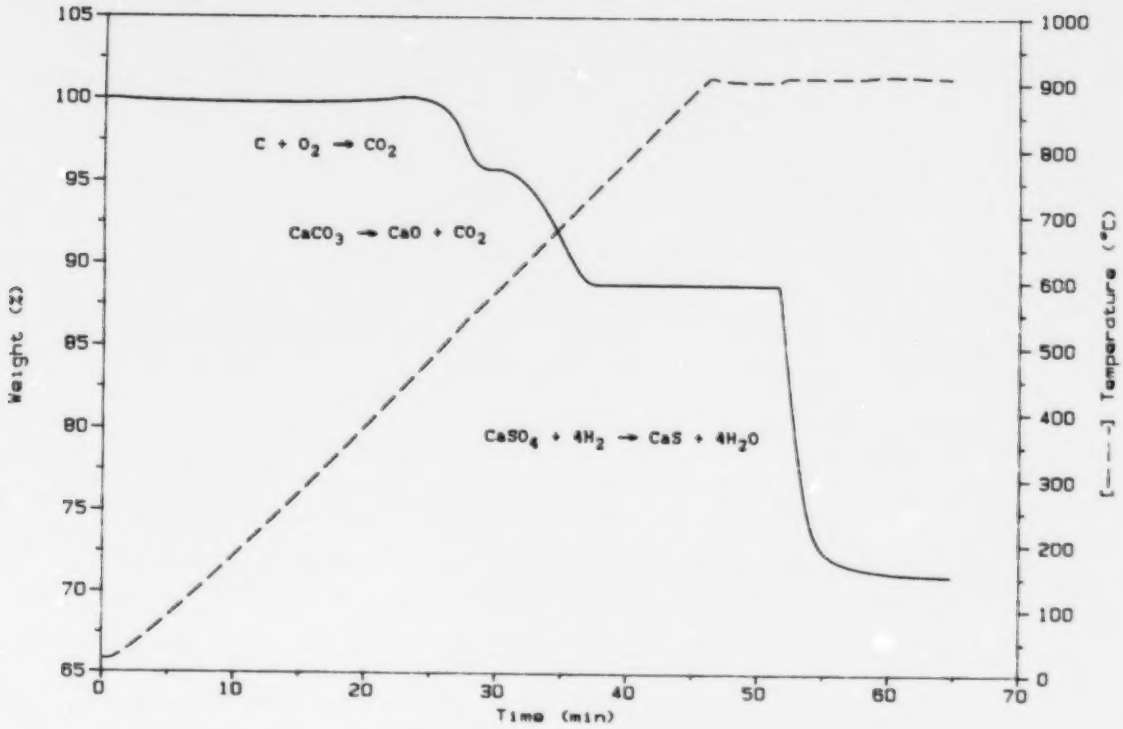

Fig. 7. TG diagram of CFB cyclone ash in N_2/O_2 and N_2 up to 900°C then isothermally in N_2/H_2. The weight losses correspond to 4.4% carbonaceous materials, 15.7% $CaCO_3$ and 37.7% $CaSO_4$

- **Project 50.62.02: Circulating Bed Combustion Systems**
  Project leader : F.D. Friedrich (ERL)

Objective:

To erect and commission a circulating FBC pilot plant at CCRL, CANMET; to identify and accelerate potential applications for circulating FBC in industry and power generation.

(a) Vanadium and sulphur capture from byproduct coke

MSL's project element was to investigate emissions of SO_2 and heavy metals, i.e., Ni and V; their capture with limestone, and corrosive effects from the combustion of tar sands byproduct coke in a circulating fluidized bed. Two major combustion test series were conducted last year in MSL. A pilot-scale circulating fluid bed unit; the first with Syncrude coke and limestone and

the second with Minto coal and three New Brunswick limestones. Approximately 30 one-day runs were done with each fuel. The results of that work were evaluated this year and a report written. Metal corrosion probes from each series were examined by the PMRL Corrosion Section. Results show that the corrosion is similar to that found in bubbling fluidized bed units, and that there is no evidence that vanadium is the cause of the corrosion. The vanadium is captured as calcium vanadate.

In the Syncrude coke trials, greater than 90% of the sulphur, 93% of the vanadium and essentially all the nickel captured was a Ca/S ratio of 2.0. Combustion trials with Minto coal and New Brunswick limestones resulted in lower than expected sulphur capture, 70-75%, and combustion efficiency, 88%. There appears to be a correlation between the sulphide content of the CFBC ash and the SO_2 capture in the combustion trials with the Minto coal.

(b) CFBC modelling status

A large sample (up to 10 g) TGA system is currently being developed as part of the modelling study on SO_2 capture in CFB combustors. The system will provide the necessary sulphation parameters for mathematical modelling. It can also be used to screen limestones, in a finer size range than is possible in the fluid bed reactor, for use in CFB combustors. A mathematical model of SO_2 retention in CFBC has been developed and is currently being refined to take into account particle size distribution.

Reports:

- Hamer, C.A., Liang, D.T. and Kearns, J.B. "Combustion trials with Syncrude coke and Minto coal in the Mineral Sciences Laboratories circulating fluidized bed combustor: sulphur and metals capture and metallic corrosion"; Division Report MSL 87-92 (IR).

- Liang, D.T., Hamer, C.A. and Kearns, J.B. "The design and operation of a small scale circulating fluidized bed combustor"; Division Report MSL 87-7 (OP&J).

MINERAL DEVELOPMENT AGREEMENTS

Manitoba

Under the Research and Technology Sector of the Canada/Manitoba Mineral Development Agreement, CANMET's Mineral Sciences Laboratories are responsible for delivery of the federally funded Processing Technology projects. During FY 1987/88 there were 10 active federally funded processing projects with forecast expenditures of $879K.

The economic evaluation of the application of the GCM process to HBMS copper concentrates has been completed. In addition a separate CANMET report has been issued comparing the GCM process with other alternatives for reducing SO_2 emissions at the HBMS copper smelter.

Under the project on the recovery of gold and silver from zinc pressure leach residues a comparative economic evaluation of CANMET pyrometallurgical method versus hydrometallurgical methods is nearing completion.

A project on pyrrhotite rejection is progressing on schedule and has shown that emphasis on resolving the smelter energy balance due to high levels of pyrrhotite is required. A revised project proposal is currently under review. The Phase II work on recovery of metals from zinc smelter oxide tailings has been initiated under contract.

The work on applied mineralogy on HBMS Trout Lake ore has been completed. As well, the work on examination of mill products at the Trout Lake and Flin Flon concentrators is well underway. The Snow Lake concentrator will also be included in this program. The two shared-cost contracts at Ruttan Mine on column flotation and flotation process control are behind schedule mainly due to personnel changes when HBMS took over from Sherritt Gordon.

The Phase IV work on the Bird River Chromite deposits has been completed. Prefeasibility studies indicate that the production of 304 stainless steel hot band is economically and technically viable. As well, the inclusion of a chrome chemical production facility on the front end of the stainless steel facility enhances the overall technical viability and economics.

New Brunswick

The Canada-New Brunswick MDA managed six contracts during the fiscal year 1987/88, three of these were on-going from previous years and three contracts were let to initiate new projects. The project to evaluate aggregates for alkali reactivity is continuing. In connection with the potash industry, image analysis techniques are being used to optimize processing circuits in the potash concentrators and the first phase of the project to study the use of waste salt as backfill in the mine was completed. A second-phase contract was awarded to test the use of salt backfill in instrumented stopes in the mine. Two further contracts were awarded in 1987/88; to study the use of CO_2 as a monitor for an underground mine ventilation system and to study methods of cyanide leaching of gold and silver at sub-zero temperatures. The use of CO_2 to monitor a mine ventilation system will allow the maintenance of higher quality mine air, and will detect changes in air quality more rapidly than is presently possible. The project to study cyanide leaching at sub-zero temperatures is aimed at extending the operation of gold heap leaching plants into the winter months, to improve their productivity.

New Brunswick's complex sulphide orebodies have relatively poor metal recoveries and present technology is pollution-prone; studies under the MDA to develop new technology to deal with these concerns using the CANMET ferric chloride leach process have been completed. Another project, concerned with the province's large but low-grade manganese deposits, has also been completed. This project involved a feasibility study investigating processing technologies to extract a marketable manganese product from the deposit.

The Canada-New Brunswick MDA is entering the last year of the agreement in 1988/89. Several projects are expected to be initiated early in this fiscal year to complete the terms of the agreement. These projects involve the non-destructive testing of mine shaft wire ropes, the development of a mine services software system to integrate data from surveying, geology and mine planning and the investigation of methods to reduce and control acid generation from pyritic mine waste sites.

Newfoundland

The four non-mining related projects under the Mining and Minerals Technology Program for which CANMET-MSL was responsible cost $440K during FY 1987/88.

The Evaluation of Point Leamington Deposit has been completed. Satisfactory recovery levels and concentrate grades are attainable only from the High Grade Zinc Zone, provided that the grind is very fine (90% minus 400 mesh). The final economic feasibility will depend mainly on the quantity of such High Zinc Ore in the Noranda's Point Leamington Deposit.

Iron Ore Recovery at Scully Mine Phase I, Quantitative Mineralogy and Phase II, Bench and Small Scale Pilot Tests have been completed. Phase III Pilot Plant Tests at the Concentrator has started. Results of Phase I suggested the necessity of improving the circuit grinding/classification and introducing re-grinding and re-processing the middlings. Phase II confirmed these suggestions and revealed that there is a potential for increasing the iron unit recovery at probably up to 10%. Overall improvement of relations Fe to Mn may, however, be difficult to achieve.

The Evaluation of Binders for Iron Ore Pellets at the Iron Ore Canada Part 2 has started. Trying new, custom-taylored Peridur and other binders gives promising results.

The Evaluation of Aggregates for Potential Alkali Reactivity was studied. Petrographic examination of concrete core samples showed that the reaction is evident. This will influence future choice of aggregates for offshore structures. Investigating mechanical properties and long-term durability of concrete with local aggregates and cement for potential applications in offshore structures has started.

Copper recovery and cyanide regeneration as design parameters for Hope Brook Gold have been studied within a small contract let to CELEC Inc.

Nova Scotia

The Research and Technology Sector of the Canada-Nova Scotia MDA managed eight contracts costing $646K during FY 1987/88.

The study on alkali reactivity of several Nova Scotia concrete aggregates continued, as did laboratory and field tests on the use of Lingan and Point Tupper fly ashes. A contract on the preparation of fillers and extenders

from certain Nova Scotia industrial minerals was left incomplete by the death of the principal investigator, but will be completed as nearly as possible by CANMET. The first phase of a three phase project investigating the production of barium chemicals from Nova Scotia barite was completed. There exists plentiful barite reserves in Nova Scotia, but conversion to chemicals may require higher grade concentrates than producible.

A brief study on the possibilities of producing potassium phosphate fertilizers in Cape Breton was completed. New technology, currently under development in Saskatchewan may have good potential for economic implementation. A project to evaluate commercial production of magnetite from the Bass River deposit continued, as major pilot test is planned mid-1988.

Work on the potential use of anhydrite as mine support gave very encouraging results; commercialization of its use is expected within two years.

Saskatchewan

The Science and Technology Sector (Sector B) of the Saskatchewan-Canada MDA managed six contracts during the fiscal year 1987/88. All of the contracts were either continuation or a second phase of the previous year's work.

In process research, pilot scale tests were conducted on heavy media separation and dry magnetic separation at Central Canada Potash and at Cominco fertilizers. Both technologies are showing promise for the Northern Saskatchewan potash mines particularly for capacity expansion. A project on electrostatic separation was discontinued. An empirical system to determine product was developed. Projects were completed on regional subsidence underground (development of predictive models), application of university research on micro seismics, acoustic emission and geotomography, and a method to predict location of structured anomelier that can permit brine inflow.

Five of the six projects were co-funded with the potash industry; total expenditure was $406.1 of which 214.5 was by the potash industry and 191.6 by CANMET.

PART B. GENERAL SERVICES AND OPERATIONS

CHEMICAL LABORATORY

Manager: H.F. Steger

Summary of Analytical Services

The figures tabulated below refer to the number of analyses performed by the Chemical Laboratory in support of CANMET programs in the period from 01 April, 1987 to 31 March, 1988.

Sub-Activity	No. of Determinations
Mineral Processing	
30.05.01	288
30.05.99	17
30.13.02	54
30.13.04	281
30.13.06	48
30.13.99	121
30.21.02	1922
30.29.01	41
30.29.05	9
30.37.01	26
30.45.01	1497
30.45.99	9
30.52.02	4109
30.52.03	2437
30.52.04	39
30.52.05	906
30.52.07	6
30.52.99	972
30.61.01	2315
30.61.02	6256
30.61.04	299
30.61.99	3000
30.69.01	626
30.69.02	53
30.69.99	85
30.77.01	2432
30.77.02	314
30.86.01	3556
30.86.02	606
30.86.03	3109
30.86.04	41
30.86.99	524
	35935
Coal Mining and Preparation	
20.79.01	6
Fuels Technology	
50.62.01	22
Metals and Materials	
70.04.01	1658
70.04.02	126
70.04.03	453
70.04.05	24
70.04.06	24
70.04.07	60
70.04.08	1107
70.04.17	297
70.18.01	158
70.27.01	79
70.27.03	494
70.27.09	282
70.27.10	50
70.54.01	648
70.54.02	173
70.54.04	185
70.65.01	19
70.65.03	18
70.91.01	845
70.91.06	278
70.91.08	54
70.91.36	114
	7146

Total Number of Determinations = 43109

EXTRACTIVE METALLURGY LABORATORY

Physical Chemistry Section

Head: A.H. Webster

Thermal Analysis

Sub-Sub-Activity	No. of Tests
30.29	22
30.61	10
30.86	8
30.77	7
50.62	5
70.54	4
Total	56

Computer Programming and Services

Sub-Sub-Activity	No. of Tests
30.45	1
30.69	2
30.86	1
Total	4

Infrared Spectroscopy

Sub-Sub-Activity	Samples Investigated
30.29	12
30.52	2
30.61	14
30.69	2
Total	30

MINERAL PROCESSING LABORATORY

Process Mineralogy Section

Head: J.L. Jambor

Summary of Mineralogical Services

Sub-Sub-Activity	SEM	Microprobe	Image Analyzer (Jobs)	X-ray Diffraction (Jobs)
30.05	22	378	10	15
30.13	-	-	8	30
30.21	-	-	-	6
30.29	41	26	-	162
30.37	31	-	-	12
30.45	162	-	-	7
30.52	245	106	1	93
30.61	89	-	2	16
30.77	171	151	-	754
30.86	4	47	2	314
50.62	19	10	-	-
70.76	-	214	-	-
Totals	784	932	23	1409

Lapidary, Mineral Separation and Other Services

Services	No. Completed
Polished Sections	1059
Thin Polished Sections	54
Magnetic Separations	41
Crushing and Screen Analyses	129
Heavy Liquid Separations	103
Low-Temperature Ashing	4
Synthesis of Standards	1

INDUSTRIAL RESEARCH ASSISTANCE PROGRAM (IRAP)

Project No.	Project	Industry	Scientific Authority
L2730-1161	Low Firing Mould Process	DPCI	A.K. Kuriakose
L2730-1264	Agitated Flotation Column	Hydrochem	T. Cienski
L2730-0442	Development of Solid Sodium Electrolytes	Almax Ind.	T.A. Wheat
L2730-0938	Low Permeability Fibrous Concrete	Gemite Unique Products Inc.	V.M. Malhotra
L2730-1064	Biorecovery of Selenium	CMS	R.G.L. McCready
L2730-0634	Cement-Based Dry-Bagged Construction Products	Target Products	H.S. Wilson
L2730-0722	Enhanced Recovery of Asbestos Fibre Using Wet Milling Process	Cassiar	D.M. Doyle
L2730-0723	Silica Fume Shotcrete	Target Products	H.S. Wilson
L2730-0786A	Underground Biological In-Place Leaching of Uranium Ore	Denison Mines	R.G.L. McCready
L2730-0870	D.C. Plasma Arc Furnace	Inco Ltd.	J.M. Skeaff
L2730-0969	Column Flotation of Lead and Zinc Sulphides	Cominco Ltd.	D.M. Doyle
L2730-1078	Chara Process: Biological Polishing of Alkaline Effluents	Boojum	R.G.L. McCready
L2730-1107	Nitrate Based Gold Recovery (NITRAUR Process)	Hydrochem	K.E. Haque
L2730-1184	Process Control and Expert System for Oil Sand Extraction	Syncrude/Edmonton	D.M. Doyle
L2730-1199	Recovery of Platinum, Palladium, and Rhodium from Spent Automotive Catalysts	Platinum Lake	G.M. Ritcey
L2730-1202	Improved Iron Recovery	IOC	W.H. Cameron

COST RECOVERY CONTRACTS

025242 - Image analysis of sulphide flotation products (Portugal)

025245 - Image analysis mineralogy

025269 - Mineralogy and liberation study of copper circuit products

025270 - PGM concentrate recovery for Lac des Iles

025285 - Production of aluminum reference materials

025288 - SEM imaging

025289 - Transfer of image-analysis technology

025293 - Mica processing

025295 - Consultative services for laboratory set-up

025299 - Preparation of three colluvial soil samples

025500 - Consultative sub-sub contract

025502 - Platinum extraction pilot plant

025503 - Image analysis goldstrike ore

025506 - Building stone - testing evaluation

025507 - Dewatering and calcining of lime

025510 - Microbiological assessment of tailings materials

025511 - B.C. olivine

025512 - Mode of occurrence of titanium for Q.I.T.

025513 - Treatment of Alcan spent potlines

025514 - Sharper alloys

025515 - Treatment of Hosco Heva refractory gold ore

025516 - Upgrading and pelletizing ilmenite ore fines from Q.I.T.

025517 - Consultation on study of platinum-bearing chromite deposits

025518 - Mineralogical characterization of placer gold grains

025521 - Mineralogical study of Wellgreen Pt, Cu, Ni deposits - Yukon

025522 - Pilot plant testing to recover PM from CRM sweeps

025523 - Mine and tailings reclamation studies

025524 - Consultation on recovery of precious metals

025525 - Analyses from Tulameen chromite

025526 - Royal Canadian Mint

025527 - Process control and expert system for oil sand extraction

025528 - Emission spectrometric analysis of titanium dioxide

025529 - Cyanide and metals recovery from Merrill-Crowe barren solutions

025531 - Preparation of gold-bearing rock reference samples

025532 - Evaluation of ion exchange resins

025533 - Review bacterial leaching activities and plans

025534 - Image analysis studies Iron Ore Company

025535 - Analysis of strontium carbonate/oxide samples

025536 - Preparation of pressed powder elemental standards

025542 - Use of MSL radiation counting facilities

SPECIAL PROJECT

Nonferrous Smelter Study

- **Project leader: W.J.S. Craigen**

Objective:

To assist Canada's nonferrous smelter industry in the development and implementation of new and improved technologies for smelter modernization, which will substantially reduce gaseous (SO_2) emissions while increasing the industry's productivity and international competitiveness.

Background:

The original objectives of the Nonferrous Smelter Study have, for the most part, been achieved with the publication of two EMR special reports; one on nickel and copper, and one on lead and zinc. Major emphasis in the project is now being directed towards implementation of the technology development

initiatives documented in the EMR reports, and described in more detail on a site-specific basis in the CANMET Technological Profiles. At present, government assistance to facilitate initiation of the technology development projects is being obtained from the following sources: DRIE IRDP; Federal/ Provincial MDA's; Unsolicited proposals (CANMET/DSS); IRAP and NSERC.

Status:

Progress reports on Inco's SO_2 control strategies for Sudbury indicate that the new smelter technology to achieve SO_2 emission targets will be flash smelting of a bulk Ni/Cu concentrate. This has the advantage of utilizing Inco's flash smelting expertise, and is essentially the route recommended by CANMET in the EMR Special Report on nickel and copper. It is by far the most energy efficient alternative, does not require a slag cleaning facility and should significantly reduce costs in the mill, since selective concentrates do not have to be produced. The 1994 SO_2 emission targets should be attainable without capturing SO_2 from the converters. This will provide time for development of a continuous converting process which would facilitate SO_2 capture from the converters to meet possible future reductions in SO_2 emissions after 1994. In addition, Inco may not have to build a new acid plant, since SO_2 concentrations from the flash smelter will be high enough to be pipelined to the existing IRDP acid plants for conversion to acid. The economics of this route, which includes acid plant upgrading from single to double contact, are presently being investigated.

There are a number of problem areas related to flash smelting of bulk Ni/Cu concentrates, Ni/Cu separation in matte processing, flash converting of MK copper (from matte processing) and SO_2 capture from fluid bed roasting of NiS (also from matte processing). CANMET, in co-operation with NSERC and UBC, has initiated a project utilizing the flash smelter at UBC, to assist Inco in evaluating smelting parameters for MK copper and Ni/Cu concentrates. A second co-operative project on high pressure tuyere blowing is presently being negotiated, with potential participants including Canadian Liquid Air, UBC, CANMET and DRIE. Other co-operative CANMET/Inco projects are also being investigated for initiation in 1988/89.

The Inco Sudbury IRDP project on pyrrhotite (Po) rejection is progressing satisfactorily. Operating problems in the demonstration plant have been resolved and the plant has been continuously operated on a campaign basis for about nine months. However, there is still considerable doubt that target objectives with respect to Po rejection and nickel and PGM recovery can be achieved by the scheduled completion date of June, 1988. In addition, with the introduction of the bulk smelting route, the best way to obtain the required level of Po rejection to achieve the SO_2 emission goals is not nearly as well defined. The SO_2/air method of Po rejection may not be the best solution to the problem. There is therefore still a great deal more R&D required, particularly with the introduction of the new mill rationalization scheme which would concentrate all milling operations at Clarabelle. Inco's list of scheduled activities for 1988 indicates that all aspects of milling/beneficiation for Po rejection will be investigated. This is far beyond the original scope of the DRIE/Inco Po rejection project.

Falconbridge has three, DRIE IRDP supported, technology development projects underway to meet their projected targets for smelter modernization and SO_2 control. The three projects are "Increased Roast, Converter Slag Cleaning and Pyrrhotite Rejection". All projects are proceeding satisfactorily and on schedule. In the Po rejection project, new magnetic separation equipment and techniques have been tested with encouraging results and a 3' x 45' flotation column has been designed, installed and commissioned. Column flotation is being tested for both Cu/Ni separation and Po/Pn separation.

In the increased roast project, the secondary cyclones in the roaster circuit have been successfully by-passed without affecting acid plant operation and air in leakage has been reduced by 50%. Cooper coolers have been installed and demonstrated in the electric furnace and modelling of the converter aisle operation to handle the higher grade smelter matte is progressing satisfactorily. In the converter slag cleaning project a cheaper reductant has been tested with encouraging results and analysis of operating data is continuing to identify major factors affecting metallurgical performance and refractory life.

Potential CANMET/Falconbridge co-operative projects for 1988/89 are being investigated, including a request from Falconbridge to sponsor a "Flotation Reagent Symposium" at Sudbury.

A submission from HBMS for government financial assistance to implement smelter modernization at Flin Flon has been received. Total costs are estimated at $100 million; $75 million for the Zinc Pressure Leach (ZPL) plant and $25 million for retrofitting the copper smelter. The latter would require electric furnace components from the slag fuming plant, which would be shut down when the ZPL is installed, and modification of one of the existing converters to allow operation as a Noranda Reactor. Operating cost savings from smelter modernization would be about $20 million/y, with a reduction in SO_2 emissions of 29%, all of which would result from implementing the ZPL process. There would be no SO_2 reduction from the copper smelter.

A federal/provincial working group has been established to deal with the HBMS application for financial assistance. EMR is represented by MPS, with CANMET providing technical input as required.

There are three CANMET/HBMS projects under the Manitoba MDA which are aimed at improving the economic viability of the ZPL process. These are:

- Gold/silver recovery from ZPL oxide residues;
- Gold/silver recovery from ZPL sulphide residues;
- Improved zinc/copper separation during production of selective concentrates.

Work on gold/silver recovery from oxide residues has been completed at Sherritt Gordon and a final report evaluating the technical-economic viability of the process will be completed by May, 1988. Testwork at CANMET on a pyrometallurgical alternative for gold/silver recovery from sulphide residue has also been completed. The comparative economic evaluation of the technically feasible alternatives for the ZPL sulphide residue is being undertaken

directly by HBMS, and a report is expected by April, 1988. Methods for improving zinc/copper separation are being tested on a production scale at HBMS based on preliminary studies at CANMET and University of Manitoba.

Work on the Cominco/CANMET shared-cost contract for the "Treatment of Hydrometallurgical Residues" has been initiated by Cominco. An agreement has also been reached with respect to ownership, patenting and licensing of the technology. The project is aimed at improving the separation and recovery of sulphur and precious metals from hydrometallurgical process leach residues.

Excellent progress has been made over the first year on the UBC/Cominco/NSERC project on modelling of the ZPL process. The Cominco strike has allowed new sample tubes to be installed in the autoclave to obtain better samples for verifying model calculations.

The CANMET/IRAP/Inco Sudbury shared-cost contract on Plasma Reduction/Melting for utility nickel is progressing satisfactorily. The furnace has been operating since early September, producing nickel from nickel oxide. Major problems still to be resolved are high carbon in the nickel product, erosion of the refractory brick and high electrode consumption.

The CANMET shared-cost contract with Inco Sudbury, on "Copper Refinery Electrolyte Control" is now complete and a final report has been issued. Although the control techniques developed could not be successfully applied to the refinery circuit, the knowledge gained was significant and is expected to be beneficial to the operation of the copper electrowinning plant.

Noranda has cancelled the second trial run to process 2000 t of Horne smelter dusts at Nova Pb. A decision has been made to purchase a short rotary furnace for processing these dusts, along with normal BMS lead smelter dusts, at Belledune. This EC/EMR DRECT program project has therefore been terminated.

The DRIE IRDP project with Tibur Howden on plasma smelting for metals recovery from ferrous and nonferrous flue dusts has been terminated as a result of Howden's withdrawal from the project. The plasma furnace was operated intermittently over a one year period at average feed rates of 0.4 tph of steel mill dusts, and a final report has been written. Although the testwork was reasonably successful in producing an environmentally acceptable discard slag, much more testwork is required to optimize the process parameters and determine economic viability.

Construction of the Noranda Horne smelter acid plant has been awarded to Chemetics Int'l. Cost of the acid plant is estimated at $125 million for 600,000 t/y capacity.

Construction of Cominco's new lead smelter (QSL process) at Trail, B.C. is proceeding on schedule.

Progress on the CANMET supported U.P. (McMaster University) on reduction smelting has indicated that H_2S production from CaS slag is not technically feasible. However, H_2S can be produced from Na_2S slag. Since sodium salts

cannot be considered as a practical or economic medium for reduction smelting, this technology development project will be assessed on the basis of its potential application for conversion of SO_2 to elemental sulphur.

Alternatives for SO_2 capture and/or sulphuric acid use are being investigated in two projects under the N.B. and N.S. MDA's. Investigations include the production of potassium sulphate and/or potassium phosphate fertilizers. Preliminary reports on process options and potential markets have been issued by British Sulphur on K_2SO_4 and by Kilborn on monopotassium phosphate (MKP). A large number of technological alternatives have been identified with no clear cut winners defined to date.

During 1987/88 CANMET has continued to be involved in a technical advisory capacity to Enhanced Recover Systems (ERS) and to RPC on the evaluation of the SRL process pilot plant at Chatham, N.B. A final report assessing the technical and economic viability of the process has been issued by ERS and approved by the technical advisory committee. A contract to an outside consultant to verify the engineering design and capital and operating costs has just recently been let.

The following smelter development projects are being carried out under the Manitoba MDA:

(a) Pyrrhotite rejection: Inco Thompson

Investigations include flotation reagents, column flotation, regrind studies, magnetic separation and the effect of Po removal on smelter heat balances. The project is about 50% complete at this time. Completion date has been extended to April, 1989. At Inco's request discussions were held on possible new shared-cost projects for MDA support. These could include a refinery modernization project to eliminate reverts to the smelter and minimize the energy balance problems associated with Po rejection.

(b) GCM hydrocopper process: HBMS/BDA

The HBMS/CANMET engineering and economic evaluation of the GCM process was presented at the annual MDA review meeting. In addition, economic comparisons of the GCM process with other possible alternatives for SO_2 control at HBMS were documented, and these data have been published in a separate CANMET/HBMS report, and presented at an International Copper Conference in Chile. Essentially, the data show that at the present time there is no technically and economically viable alternative to reduce SO_2 emissions from the HBMS copper smelter. The GCM process offers the best long-term potential when compared to pyrometallurgical alternatives. However, continuous pilot-scale testing of the process is mandatory and an efficient on-site facility for recovering gold from GCM process leach residues must be developed. Total development costs could exceed $5 million. Unless environmental regulations require substantial reductions in copper smelter SO_2 emissions it is highly unlikely that HBMS or any other Canadian copper producer will commit funds to the further development of the process. This MDA project therefore, is essentially terminated unless SO_2 emission regulations force industry to re-evaluate the situation. Interest in the GCM process has been expressed by

two engineering consulting firms, Fenco Lavalin (Canada) and Utah International (USA).

(c) Metal recovery from oxide tailings residue: HBMS/Sherritt

A final report on the Phase I studies has been issued by Sherritt. The results look encouraging and HBMS has committed $40K to initiate Phase II studies. MDA funds will be available in 1988/89 to complete the project.

Contracts:

- Reqn. 5-9030, "To develop sulphur reducing mineral beneficiation techniques and perform sulphur emission tests at Inco Smelter, Thompson, Manitoba", Inco Ltd. S.A. - W.J.S. Craigen.

- Reqn. 5-9129, "Gold-silver recovery from zinc pressure leach residues Phase I", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

- Reqn. 5-9220, "Metal recovery oxide residues", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

- Reqn. 5-9264, "Gold-silver recovery from zinc pressure leach residues Phase II", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

- Reqn. 6-9191, "Gold-silver recovery from zinc pressure leach residues Phase III", Hudson Bay Mining and Smelting Co. Ltd. S.A. - W.J.S. Craigen.

CANMET SYMPOSIUM AT VAL D'OR

A CANMET symposium entitled "CANMET, Partner with the Quebec Mining Industry" was presented in Val D'Or on February 24 and 25, 1988. The main objective of the event was to promote contact and provide a forum for the exchange of ideas between government researchers and mining industry representatives. MSL staff presented poster-type displays and also arranged the technical sessions. The emphasis in this part of Quebec is on gold mining and milling, which was reflected in the technical content of the seminar.

Papers were presented as follows: MSL support to mining industry by L.L. Sirois, computer application in mineral processing by D. Laguitton, mineralogy of gold by L.J. Cabri, recovery of gold from solutions by G. Deschênes, cyanide destruction and tailings management by G.M. Ritcey et al., use of slag for cemented mine backfill by V.M. Malhotra et al., mineral development agreements by D.M. Doyle et al. Workshops on mineralogy, mineral processing assisted by computer, slag backfill, cyanidation and cyanide treatment were organized. Displays and video tapes of MSL projects and services were also part of the seminar.

The response from the industry was very good and attendance exceeded expectations.

PART C. REPRESENTATION ON TECHNICAL COMMITTEES

INTERNATIONAL

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

Barkley, D.J.
- Member, CAC/ISO/TC 26/SC 1, Copper and Copper Alloys;
- Member, CAC/ISO/TC 17/SC 1, Analysis of Steel and Cast Iron;
- Corresponding Partner, CAC/ISO/TC 17/SC 1/WG-12, Plasma.

Chen, T.T.
- Member, CAC/ISO/TC 175, Fluorspar.

Graham, J.A.
- Member, CAC/ISO/TC 183, Copper, Lead and Zinc Ores and Concentrates;
- Member, CAC/ISO/TC 183, Hosting Committee for the International Conference to be held in Ottawa in May, 1988;
- Corresponding Partner, CAC/ISO/TC 183/WG-2, Silver and Gold in Copper Concentrates.

Hole, J.C.
- Member, CAC/ISO/TC 102, Iron Ores;
- Chairman, CAC/ISO/TC 102/SC 2, Iron Ores.

Mainwaring, P.R.
- Member, Joint CAC/ISO/TC 146/147/SC 3, WG1, Detection Asbestos Fibre in Air.

Malhotra, V.M.
- Chairman, CAC/ISO/TC 71, Concrete (SC 1 and SC 3).

Smith, C.W.
- Member, CAC/ISO/REMCO, Committee on Reference Materials.

Steger, H.F.
- Chairman, CAC/ISO/REMCO, Reference Materials.

Sutarno, R.
- Member, CAC/ISO/TC 102, Iron Ore;
- Chairman, CAC/ISO/TC 102/SC 1, Sampling Subcommittee;
- Convener, ISO/TC 102/SC 2/WG 12, Chemical Analysis Subcommittee, Working Group on Evaluation of Statistical Data;
- Canadian Representative to Study Group on Reference Materials - Iron Ores, CAC/ISO/TC 102/SC 2;
- Member, CAC/ISO/TC 69, Application of Statistical Methods;
- Chairman, CAC/ISO/TC 69/SC 6, Measurement Methods and Results;
- Canadian Representative to ISO/TC 69/SC 6/WG 1, Revision of ISO 5725;
- Convener, ISO/TC 69/SC 6/WG 4, Joint Working Group between ISO/TC 69 and ISO/REMCO on Statistical Aspects of Reference Materials;

- Member, CAC/ISO/REMCO, Reference Materials;
- Member, CAC/ISO/TC 183, Copper, Lead and Zinc Ores and Concentrates;
- Convener, ISO/TC 183/WG 10, Statistical Evaluation of Test Programs.

Wilson, J.M.D.
- Member, CAC/ISO/TC 24, Sieves, Sieving and Other Sizing Methods;
- Member, CAC/ISO/TC 102, Iron Ores (SC 3 and SC 5).

INTERNATIONAL MINERALOGICAL ASSOCIATION

Cabri, L.J.
- Canadian Representative, Commission of Ore Microscopy;
- Rapporteur, Analytical Methods Subcommittee, Commission of Applied Mineralogy.

Chen, T.T.
- Member, Committee on Sulphosalts.

Petruk, W.
- Member, Applied Mineralogy Committee.

INTERNATIONAL COMMITTEE ON APPLIED MINERALOGY IN THE MINERAL INDUSTRY

Petruk, W.
- Canadian Representative;
- Liaison Representative.

INTERNATIONAL ATOMIC ENERGY AGENCY

Campbell, M.C.
- Member, Consultants Group on Uranium Extraction.

Dalton, J.L.
- Consultant, Analytical Techniques in Uranium Exploration, Development and Ore Processing.

INTERNATIONAL ENERGY AGENCY

Ahmed, S.M.
- Canadian Technical Contact Person to the I.E.A. for Task VI (Photocatalytic Water Electrolysis) for the Program of Research and Development and Production of Hydrogen from Water.

MISCELLANEOUS

Dutrizac, J.E.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam.

MacKinnon, D.J.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam.

McCready, R.G.L.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam.

Malhotra, V.M.
- Member, Committee on NDT of Concrete.

Mirkovich, V.V.
- Director, International Thermal Conductivity Conference;
- Member, Editorial Board, International Journal of Thermophysics, Plenum Press, N.Y.

Ritcey, G.M.
- Member, International Solvent Extraction Technology Committee;
- Editor, International Journal of Hydrometallurgy, Elsevier Pub. Co., Amsterdam;
- Member, Editorial Board, Journal of Separation Process Technology, C. Lildwell Press, England;
- Member, Editorial Board, "Science and Technology of Tributyl Phosphate", C.R.C. Press, Pub.;
- Member, Editorial Board, "Extractive and Process Metallurgy", Gorden & Branch, Pub.;
- Member, International Conference on Separation Science and Technology-International Committee;
- Chairman, International Conference on Separation Science and Technology, Second Conference.

Sirois, L.L.
- Member, International Scientific Committee of the International Mineral Processing Congress;
- Member, 10th International Coal Preparation Congress, Organizing Committee.

Soles, J.A.
- Member, Process Mineralogy Committee, AIME;
- Member, Organizing Committee, 7th International Conference on Alkali Reactivity;
- Member, Subcommittee on Aggregate/Concrete Testing & Standards, Canadian Standards Association.

Stefanski, M.J.
- Member, 10th International Coal Preparation Congress, Technical Program Committee.

CANADA

FEDERAL

Andrews, P.R.A., Doyle, D., Lamothe, J.M., Soles J.A., Wang, S.S.B., Wilson, H.W.
- Members, Interbranch Liaison, Industrial Minerals (ILIM).

Bedard, P.
- Member, MSL-EDP Committee.

Bell, D.H.
- Co-chairman, Technical Subcommittee for Mining and Mineral Technology, CANADA/NEWFOUNDLAND Mineral Development Agreement.

Campbell, M.C.
- Chairman, BIOMINET;
- Chairman, MSL-EDP Committee;
- Member, CANMET EDP Acquisitions Committee;
- Member, Uranium Resource Appraisal Group;
- Member, Biotechnology Co-ordinating Group.

Collings, R.K.
- Chairman, Interbranch Liaison, Industrial Mineral (ILIM).

John, R.D.
- Member, Advisory Committee, Second International Conference on Radioactive Waste Management.

McCready, R.G.L.
- Secretary, BIOMINET.

Pilgrim, R.F.
- Member, MSL-EDP Committee.

Stefanski, M.
- Co-chairman, Technical Subcommittee for Mining and Mineral Technology, CANADA/NEWFOUNDLAND Mineral Development Agreement.

Steger, H.F.
- Member, Interdepartmental Committee on Standards Policy.

Sutarno, R.
- Member, MSL-EDP Committee;
- Member, CANMET EDP Acquisitions Committee;
- MSL Representative to CANMET CAD Committee;
- MSL Representative to CANMET Communication and Marketing Committee.

DEPARTMENT OF REGIONAL INDUSTRIAL EXPANSION

Craigen, W.J.S.
- Member, Technical Advisory Committee for the Canada - New Brunswick Sulphation Roast Leach Pilot Plant;
- Member, Board of Directors for Enhanced Recovery Systems (ERS);
- Member, Technical Advisory Committee for Northern Smelters Modernization.

CANADA GENERAL STANDARDS BOARD

Douglas, E.
- Member, Committee GP-34, Asbestos-Cement Products.

UNIVERSITY OF BRITISH COLUMBIA
THE CENTRE FOR METALLURGICAL PROCESS DEVELOPMENT

Campbell, M.C.
- Member, Technical Advisory Board.

ENVIRONMENT CANADA

Joe, E.G.
- Member, Gold Processors Working Group.

NATIONAL SCIENCES AND ENGINEERING RESEARCH COUNCIL

Bell, D.H.
- Scientific Secretary, Grant Selection Committee, Chemical and Metallurgical Engineering.

Dutrizac, J.E.
- Member, Grant Selection Committee, Chemical and Metallurgical Engineering.

Townsend, M.G.
- Member, Committee on Technology for Silicon Integrated Circuits.

MISCELLANEOUS

CANADIAN CERAMIC SOCIETY

Ahmad, A.
- Member, Electronics and Basic Science Division;
- Chairman, Electronics and Basic Science Division, Technical Sessions;
- Judge, Ceramographic Competition.

Canaday, J.D.
- Associate Editor, Journal of Canadian Ceramic Society.

Kuriakose, A.K.
- Chairman, Ceramographic Committee;
- Associate Editor, Journal of CCS;
- Director, C.C.S.;
- Session Chairman, CCS Annual Meeting, Electronics and Basic Sciences Division.

Wheat, T.A.
- Director, Electronics Basic Science Division;
- Chairman, Publications Committee.

CANADIAN COMMITTEE ON ANALYTICAL CHEMISTRY RELATED TO CANADA'S NUCLEAR INDUSTRY

Dalton, J.L.
- Member, Organizing Committee for 4th Workshop (May 1988).

CANADIAN INSTITUTE OF MINING AND METALLURGY

Cabri, L.J.
- Representative, Special Volumes.

Collings, R.K.
- Member, Special Volumes Committee.

Doyle, D.
- Secretary, Canadian Mineral Processors Division;

Dutrizac, J.E.
- Member, Historical Metallurgical Committee;
- Member, Hydrometallurgy Section Executive;
- Member, Light Metals Committee.

Laguitton, D.
- Member, Computer Applications and Process Control Committee.

Mainwaring, P.R.
- Chairman, Mineral Sciences and Engineering Section, Metallurgical Society.

Ritcey, G.M.
- Member, Hydrometallurgy Section Executive.

Skeaff, J.M.
- Publicity Chairman, 1988 CIM Conference of Metallurgists.

CANADIAN MINERAL PROCESSORS CONFERENCE

Doyle, D.
- Secretary.

CANADIAN NATIONAL COMMITTEE FOR THE INTERNATIONAL UNION OF CRYSTALLOGRAPHY

Szymanski, J.T.
- Secretary.

CANADIAN STANDARDS ASSOCIATION

Andrews, R.P.A.
- Member, Committee on Gypsum and Lime (A.82);
- Chairman, Editorial Subcommittee.

Carette, G.G.
- Member, Committee on Cement (A.5);
- Member, Committee on Cement Admixtures.

Malhotra, V.M.
- Member, Executive Committee on Aggregates and Concrete (A.23.1, A.23.2, A.24.3);
- Member, CSA Committee (A.23.1).

Soles, J.A.
- Member, Subcommittee on Cement-Aggregate Reactivity;
- Member, Committee on Cement and Aggregate.

Sutarno, R.
- Member, Committee on Applications of Statistical Methods.

CANADIAN SOCIETY OF CIVIL ENGINEERING

Malhotra, V.M.
- Member, Technical Activities Committee;
- Associate Editor, Canadian Journal of Civil Engineering.

CANADIAN URANIUM PRODUCERS'S METALLURGICAL COMMITTEE

Dalton, J.L.
- Treasurer, Analytical Subcommittee;
- Convenor, X-ray Fluorescence Analysis Course, CANMET.

CHEMICAL INSTITUTE OF CANADA

Hole, J.C.
- Chairman, Committee of Scrutineers.

IRON ORES PROCESSORS TASK FORCE

Cameron, W.
- Chairman and Secretary.

Campbell, F.R., Doyle, D., Kuriakose, A.K., Quon, D., Stefanski, M.J., Wilson, J.M.D.,
- Members.

MINERALOGICAL ASSOCIATION OF CANADA

Cabri, L.J.
- Past President;
- Chairman, Nominating Committee;
- Chairman, Past Presidents' Medal Committee.

Szymanski, J.T.
- Associate Editor, Canadian Mineralogist.

SPECTROSCOPY SOCIETY OF CANADA

Churchill, T.R.
- Business Manager, Canadian Journal of Spectroscopy;
- Exhibits Chairman, 35th Canadian Spectroscopy Conference.

Wittwer, J.W.
- Director, Ottawa Valley Section.

TECHNICAL COMMITTEE ON ACID MINE DRAINAGE

McCready, R.G.L.
- Member, (Intnl. Airport Halifax).

UNITED STATES OF AMERICA

AMERICAN CONCRETE INSTITUTE

Malhotra, V.M.
- Member, Technical Activities Committee;
- Member, ACI Committee 114 on Research Needs in Concrete;
- Chairman, ACI Committee 226/Subcommittee on Silica Fume;
- Member, Materials Research Council;
- Member, Technical Committee (214, 226, 228 and 568).

AMERICAN INSTITUTE OF MINING, METALLURGICAL AND PETROLEUM ENGINEERS

Dutrizac, J.E.
- Member, Lead, Zinc, Tin Committee.

Mainwaring, P.R.
- Member, Process Mineralogy.

Petruk, W.
- Chairman, Methodology, Process Mineralogy;
- Member, Technical Activities Committee.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

Horton, R.E.
- Secretary, Committee E.02, Emission Spectroscopy;
- Leader, Task Group on Line Overlap in X-ray Spectrometry.

Malhotra, V.M.
- Member, Committee C.09, Concrete;
- Chairman, C.09.02.05, Subcommittee on Non-Destructive Testing of Concrete.

Sutarno, R.
- Member, Executive Committee of E-16, Sampling and Analysis of Metal-Bearing Ores;
- Member, Working Group on Sampling.

AMERICAN CERAMIC SOCIETY

Ahmad, A.
- Member, The Basic Science Division.

Kuriakose, A.K.
- Member.

NATIONAL RESEARCH COUNCIL, U.S.A. - TRANSPORTATION RESEARCH BOARD

Malhotra, V.M.
- Chairman, Committee A2 E.03, Mechanical Properties of Concrete.

CENTER FOR RESEARCH ON SULPHUR IN COAL

Moon, K.S.
- Member, Program Review Committee.

PART D. PUBLICATIONS, PAPERS, PRESENTATIONS AND REPORTS

Articles and Chapters Published in Books

Campbell, M.C., Wadden, D., Marchbank, R., McCready, R.G.L., and Ferroni, G. "In-place leaching of uranium at Denison Mines Limited in Developments of Projects for the production of uranium concentrates"; Int'l Atomic Energy Agency 151-165; Vienna IAEA-TC-453.5/11.

McCready, R.G.L. and Lakshmanan, V.I. "Review of bioadsorption research to recover uranium from leach solutions in Canada"; in Immobilization if Ions by Bio-sorption; Edited by H. Eccles and S. Hunt; Horwood Publishers 219-226; London, England; 1986.

McCready, R.G.L. "Microbiological studies on high-sulphur Eastern Canadian coals in biotechnology applied to fossil fuels"; Editor, D.L. Wise, C.R.C. Press; Boca Raton, Florida (In Press); 1988.

Papers Published in Conference Proceedings

Malhotra, V.M., Carette, G.G. and Bremner, T.W. "Durability of concrete containing supplementary cementing materials in marine environment"; Proceedings of the Katharine and Bryant Mather International Conference on Concrete Durability; Atlanta, Georgia; 1987.

Melis, L.A., Steger, H.F., Knapp, R.A., Scharer, J.M. and Smith, C.W. "Study of the state of nickel and arsenic in uranium mill tailings"; Proceedings of the International Symposium on Crystallization and Precipitation 221-229; 1987.

Mikhail, S.A. "Thermogravimetric method for the determination of major reaction products in fluidized-bed coal combustion processes"; Proceedings of the 16th North American Thermal Analysis Society Conference; ed. P.J. Kelleghan; 502-508; 1987.

McCready, R.G.L. "A review of the physical, chemical and biological measures to prevent acid mine drainage: An application to the pyritic Halifax shales"; Proc. Acid Mine Drainage Seminar/Workshop"; Environment Canada 333-355; En 40-11-7; 1987.

Sivasunderam, V., Carette, G.G. and Malhotra, V.M. "Superplasticized high-volume fly ash system to reduce temperature rise in mass concrete"; Proceedings of the Eighth International Ash Utilization Symposium; Washington, D.C.; 1987.

Papers Published in Outside Journals

Barkley, D.J., Dahms, T.E. and Villeneuve, K.N. "Permanently coated ion exchangers for liquid chromatographic determination of anionic species in samples from environmental control processes"; J Chromatogr 395:631-640; 1987.

Carette, G.G. and Malhotra, V.M. "Characterization of Canadian fly ashes and their relative performance in concrete"; Canadian Journal of Civil Engineering 14:667-682; 1987.

Hogarth, D., Chao, G.Y. and Townsend, M.G. "Potassium- and fluorine-rich amphiboles from the Gatineau area, Québec"; Can Mineral 25:739-753; 1987.

Jambor, J.L., Roberts, A.C. and Grice, J.D. "Armstrongite from the Strange Lake alkalic complex, on the Quebec-Labrador boundary, Canada"; Powder Diffraction 2:2-4.

Jambor, J.L., Carson, D.J., Stemerowicz, A. and Petruk, W. "Predictive metallurgy and bench flotation tests of massive sulphide ores from Tally Pond, Newfoundland"; Process Mineralogy VI 255-272; AIME.

McCorkell, R.H. and Silver, M. "Effect of compost and soil covers on radon emanation from uranium tailings"; CIM Bull 80:908:43-45; 1987.

Longworth, G., Townsend, M.G., Provencher, R. and Kodama, H. "Magnetic interaction in biotites and oxidized biotites"; Phys Chem. Minerals 15:71-77; 1987.

Petruk, W. "Predicting mineral liberations in ores and mill products and effect of mineral textures and grinding methods on mineral liberation"; Process Mineralogy VI, AIME; New York; 1987.

Provencher, R., Brett, M.E. and Townsend, M.G. "Super-conductivity and materials preparation in $YBa_2Cu_3O_{6+x}$"; Phys Status Solidi(a) 103:K107-K111; 1987.

Quon, D.H.H. and Bell, K.E. "Performance of magnesia-carbon bricks in vacuum at high temperature"; J. Can. Ceram. Soc. 56:39-44; 1987.

Townsend, M.G., Longworth, G., Ross, C.A.M. and Provencher, R. "Ferromagnetic or antiferromagnetic Fe III spin configurations in sheet silicates"; Phys Chem Minerals 15:64-79; 1987.

Wilson, L.J. and Mikhail, S.A. "Investigation of the oxidation of niccolite by thermal analysis"; Thermochimica Acta 112:197-213; 1987.

Presentations

Ahmad, A. "The effect of processing parameters on the properties of modified lead titanate"; Paper presented to the Electronics and Basic Science Division, at the Annual Meeting of the Canadian Ceramics Society, Toronto; February 1988.

Ahmed, S.M. "In situ studies of the field dependent photoluminescence spectroscopy of n-GaAs semiconductor electrodes"; 70th Canadian Chemical Conference, Chemical Institute of Canada; Ste Foy, Quebec; June 1987.

Ahmed, S.M. "Photoelectrochemical production of H_2O_2 on semiconductor electrodes"; 70th Canadian Chemical Conference, Chemical Institute of Canada; Ste Foy, Quebec; June 1987.

Aota, J. "Fabrication of zirconia-toughened mullite ceramics (ZTM)"; Paper presented to the Electronics and Basic Science Division, at the Annual Meeting of the Canadian Ceramics Society, Toronto; February 1988.

Aota, J. "Corrosion resistance of Doloma bricks in contact with slags from secondary steelmaking"; Paper presented to the Clay and Refractories Division, at the Annual Meeting of the Canadian Ceramics Society, Toronto; February 1988.

Barkley, D.J. "Dynamic ion exchange chromatography for the determination of rare earths in steels, alloys and advanced materials"; ION EX 87, North East Wales Institute, Wales, England; April 1987.

Canaday, J. "Measurements of the platinum/hydronium-nasicon system"; Paper presented to the Electronics and Basic Science Division, at the Annual Meeting of the Canadian Ceramics Society, Toronto; February 1988.

Carette, G.G. "Preliminary data on long-term strength development of condensed silica fume concrete"; International Workshop on Condensed Silica Fume in Concrete; Montreal, Quebec; May 1987.

Carette, G.G. "Superplasticized high-volume fly ash system to reduce temperature rise in mass concrete"; Eighth International Ash Utilization Symposium; Washington, D.C.; October 1987.

Cloutier, J.C. "A rapid fire-assay atomic-absorption method for the determination of platinum, palladium and gold in ores and concentrates: A modification of the tin-collection scheme"; 1987 Canadian-American Mineral Analysts Conference, Winnemucca, Nevada; November 1987.

Craigen, W.J.S. "A technical and economic evaluation of modernization alternatives for a Canadian copper smelter"; Copper 87, Vina Del Mar, Chile; December 1987.

Dutrizac, J.E. "The mineralogical characterization of anode slimes from the Kidd Creek copper refinery"; TMS Symposium on the Electrorefining and Winning of Copper, Denver, U.S.A.; February 1987.

Dutrizac, J.E. "Iron precipitation and iron residue stabilization"; International Group of Zinc Producers, Odda, Norway; September 1987.

Dutrizac, J.E. "An overview of iron precipitation in hydrometallurgy"; 17th Annual Hydrometallurgical Meeting, Saskatoon, Canada; October 1987.

Dutrizac, J.E. "A mineralogical comparison of the anode slimes from three Canadian copper refineries"; Copper 87, Vina del Mar, Chile; December 1987.

Kuriakose, A.K. "The effect of precursor raw materials on the tetragonal zirconia content of alumina-zirconia"; Paper presented to the Electronics and Basic Science Division, at the Annual Meeting of the Canadian Ceramics Society, Toronto; February 1988.

Kuriakose, A.K. "Developments in zirconia-toughened alumina"; Paper presented to the Electronics and Basic Science Division, at the Annual Meeting of the Canadian Ceramics Society, Toronto; February 1988.

Mathieu, G.I. "Mineralogy and intensive cleaning of Donkin-Morien coal"; COAL PREP 87 Conference, Lexington, Kentucky; April 1987.

Mikhail, S.A. "Thermogravimetric method for the determination of major reaction products in fluidized-bed coal combustion processes"; 16th North American Thermal Analysis Society Conference, Washington, D.C.; September 1987.

McCready, R.G.L. "Transformation of soil minerals and mineral extraction processes"; Applied Environmental Microbiology, Carleton University; February 10, 1987.

McCready, R.G.L. "Acid generation in mine tailings, Colloque Environment Minier du Quebec"; Val d'Or, Quebec; May 21, 1987.

McCready, R.G.L. "Current biotechnology research in the mining and petroleum sectors"; Invited Seminar, Dept. of Chem. Eng., University of Saskatchewan; June 19, 1987.

McCready, R.G.L. "Progress in the bacterial leaching of metals in Canada"; Int'l Symp. on Biohydrometallurgy, Warwick, U.K.; July 12-16, 1987.

McCready, R.G.L. and Salley, J. "Application of biotechnology to recover metals from dilute solutions"; Ann. Conf. of Metallurgists, Winnipeg, Manitoba; August 26, 1987.

McCready, R.G.L. "Transformation of soil minerals and mineral extraction processes"; Applied Environmental Microbiology, Carleton University; February 10, 1987.

McCorkell, R.H. "Fission-track determination of sub-ppb concentrations of uranium in solutions"; 193rd National Meeting of the American Chemical Society, Denver, Colorado; April 1987.

McCorkell, R.H. "Fission-track dating methods"; Seminar presented to the Department of Classical Studies, University of Ottawa, Ottawa, Ontario; January 1988.

McCorkell, R.H. "Fission-track dating methods short course"; One-day course presented to the Department of Classical Studies, University of Ottawa, Ottawa, Ontario; February 1988.

Moon, K.S. "Desulphurization of high sulphur coal"; Seminar on Coal Beneficiation, Korea Institute of Energy and Resources, Daeduk, Korea; December 1987.

Moon, K.S. "Surface chemistry in materials science"; Seminar on Surface Chemistry, Seoul National University, Seoul, Korea; January 1988.

Moon, K.S. "Physical desulphurization of coal"; Seminar on Coal Desulphurization, University of California, Berkeley, California; January 1988.

Moon, K.S. and Sirois, L.L. "Theory and industrial application of column flotation in Canada"; International Symposium on Column Flotation, Phoenix, Arizona; January 1988.

Smith, C.W. "Study of the state of nickel and arsenic in uranium mill tailings"; International Symposium on Crystallization and Precipitation, Saskatoon, Sask.; October 1987.

Smith, C.W. "Canadian compositional reference materials for uranium and thorium decay series isotopes"; Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Berkeley, California; October 1987.

Tan, K.G. "Modernized hydrometallurgical process development techniques"; TMS Fall Meeting, Palm Springs, U.S.A.; December 1987.

Tan, K.G. "Copper refinery anode slimes processing"; Magma Copper Co., San Manuel, U.S.A.; December 1987.

Townsend, M.G. "Superconductivity in $YBa_2Cu_3O_{6+x}$"; International Conference on Amorphous Materials, Malaga, Spain; May 1987.

Wheat, T.A. "Hydrogen electrolysis at 300 K using a nasicon solid proton conductor"; Paper presented at the Sixth International Meeting on Solid State Ionics, Garmish-Partenkirschen; September 1987.

CANMET Reports (CM)

CM 86-8E 30.29.01
Canaday, J.D., Kuriakose, A.K., Ahmad, A. and Wheat, T.A. "An electrochemical analysis of solid electrolyte/electrode systems"; August 1986.

CM 86-9E 50.62.01
Hamer, C.A. "Evaluation of SO_2 sorbent utilization in fluidized beds"; December 1986.

CM 86-10E 30.37.01
Malhotra, V.M. "Mechanical properties and freezing and thawing durability of concrete incorporating a ground granulated blast-furnace slag"; February 1987.

CM 87-1E 30.13.05
Petruk, W. "The MP-SEM-IPS image analysis system"; June 1986.

Special Reports (SP)

SP 86-2 30.45.01
Beaudette, L.A. and McCready, R.G.L. "Biotechnology bibliographies/bibliographies de la biotechnologie".

SP 86-8E 30.69.03
Malhotra, V.M. "Supplementary cementing materials for concrete".

SP 86-9E 30.45.03
McCready, R.G.L. "Proceedings of the 3rd annual meeting of BIOMINET".

SP 87-4E 30.13.01
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Leung, J. and Cameron, W. "Investigation to improve the dewatering of the thickeners in QCM iron ore plant"; January 1987.

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Kuriakose, A.K., Ahmad, A., Canaday, J.D. and Wheat, T.A. "The effect of composition on the properties of hydronium zirpsios"; March 1987.

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Jambor, J.L. and Owens, D.R. "Mineralogical examination of treated zinc oxide fume leach residues"; April 1987.

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Andrews, P.R.A. "Preliminary assessment of Wollastonite from Marble Mountain area, Nova Scotia"; April 1987.

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Quon, D.H.H. and Kuriakose, A.K. "Cold bonding process for making iron ore pellets - I"; February 1987.

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Cristovici, M.A. and McCarthy, D.R. "Investigation to remove the sulphides from Kidd Creek mill tailing prior to cassiterite flotation - progress report"; April 1987.

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MSL 87-79 (IR) 30.13.02
Stefanski, M.J. "Dewatering and self dewatering of concentrates: Part C-Literature Review"; May 1987.

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Andrews, P.R.A. and Kelly, W. "Beneficiation of staurolite from Barrie Township, South Eastern Ontario"; November 1987.

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Wang, S.S.B. "A study of the operation of a Jones P40 wet high intensity magnetic separator"; April 1987.

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Wang, S.S.B. and Prud'homme, P.J.H. "Recommissioning of bentonite test equipment"; December 1987.

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Bell, D.H. "The CANMET ferric chloride leach process"; December 1987.

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Sivasunderam, V. and Malhotra, V.M. "Compilation of abstracts of papers from recent international conferences and symposia on fly ash in concrete"; May 1986.

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Lumb, D.C. "CANMET annual bibliography of crushing and grinding - 1983"; April 1987.

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PART E. TECHNOLOGY EXCHANGE

PARTIAL LIST OF COMPANIES, GOVERNMENT AGENCIES, UNIVERSITIES AND RESEARCH ORGANIZATIONS WITH WHICH THE MINERAL SCIENCES LABORATORIES HAS BEEN ASSOCIATED DURING FY 1987-88

GOVERNMENT

A

Agriculture Canada

Alberta Research Council

Asbestos Research Institute, USSR

Atomic Energy Commission, USA

Atomic Energy Control Board

Atomic Energy of Canada Limited

B

Biotechnology Research Institute, (NRC)

Bureau de Recherches Géologique et Minières (BRGM), France

B.C. Department of Economic Development

B.C. Department of Energy, Mines and Petroleum Resources

B.C. Task Force on Acid Mines Drainage

C

Canadian National Railway

C (cont'd)

Cape Breton Development Corporation (CBDC)

Centro de Technologgia Mineral (CETEM), Brazil

Centre de Recherches Minérales (Quebec)

CERAM-Société Nationale de l'Amiante (SNA) Inc.

Commissoriat à l'Energie Atomique, France

Commonwealth Scientific and Industrial Research Organization, Australia

Co-ordinator Canadian-West German Technology Transfer

Customs and Excise, Revenue Canada

D

Department of External Affairs, Export Control Division

Department of Regional Industrial Expansion (DRIE)

E

Eldorado Resources Limited

Embassy of Finland

Empressa Columbiana de Minas, Bogata

Environment Canada

Ethiopian Mineral Resources Development Corporation

External Affairs Canada

F

Federal Institute for Geoscience, Federal Republic of Germany

G

Geological Survey of Canada (EMR)

H

Health and Welfare Canada

I

Institut de Recherche en Santé et Sécurité du Travail du Québec (IRSST)

Institute Para el Desarrollo y la Investigation de Los Materiales de Construcctions, Cuba

International Organization for Standardization

J

Japanese Government Industrial Research Institute

K

Korean Energy Institute

Korean Institute for Science and Technology

M

Manitoba Energy and Mines

Mining Industry Technology Council of Canada

Ministry of Building Materials, Moscow

Ministry of Defense, Argentina

Ministry of International Trade and Industry, Japan

Ministry of State for Science and Technology (MOSST)

N

National Aeronautical Establishment (NAE)

National Research Council

National Research Council-Industrial Research Assistance Program

Natural Science and Engineering Council of Canada

N (cont'd)

New Brunswick Department of Natural Resources

Newfoundland Department of Mines and Energy

Member of Parliament - D. Nickerson, Western Arctic

O

Ontario Geological Survey

Ontario Hydro

Ontario Ministry of Northern Development and Mines

Ontario Research Foundation (ORF)

P

Prime Minister's Office

Public Works Canada

R

Radio Canada

Reactive Acid Tailings Technical Work Group

Royal Canadian Mint

S

Science Council of Canada

Societé d'Aménagement de l'Outaouais

Standards Council of Canada

T

Transport Canada

W

Weizman Institute, Israel

UNIVERSITIES AND OTHER ORGANIZATIONS

A

Advanced Industrial Materials Working Group

American Ceramic Society

American Concrete Institute

Asbestos Institute

C

Canadian Institute of Mining and Metallurgy

Canadian Mineral Processors

Canadian Steel Industry Research Association

C (cont'd)

Canadian Uranium Producers Metallurgical Committee

Canadian Uranium Producers Metallurgical Committee (Analytical Subcommittee)

Cape Breton Development Corporation

Carleton University

Cement and Concrete Association of Australia

Cement and Concrete Institute

Chalmers University of Technology

Collège de la Région de l'Amiante

D

Dalhousie University

E

École Polytechnique

I

Idaho National Energy Laboratory

Industrial Materials Research Institute (IMRI)

International Atomic Energy Agency

International Energy Agency

Iron Ore Technical Task Force

L

Lab Nacional de Engenharia E Technologgia Industri, Brazil

Laurentian University

Laval University

M

McGill University

Mining Association of Canada

N

National Institute for Cement and Building Materials

New Brunswick Electric Power Commission

New Brunswick Research and Productivity Council

O

Ontario Research Foundation

Ottawa Board of Education

P

Portland Cement Association

Q

Quebec Metal Mining Association

Q (cont'd)

Queen's University

S

Saskatchewan Research Council

T

Technical University of Nova Scotia

U

Université de Québec

University of Antwerp

U (cont'd)

University of British Columbia

University of Calgary

University of Cuzco, Peru

University of Manitoba

University of New Brunswick

University of Ottawa

University of Sherbrooke

University of Texas

University of Toronto

University of Waterloo

University of Western Ontario

INDUSTRY

A

Acres Limited

Advanced Industrial Materials Working Group

Advanced Materials Engineering Centre Corporation (AMEC)

Agra Industries Limited

Alberta Opportunity Company

Alcan International Limited

Algoma Steel Corporation

Almax Industries Limited

Aries Image Analysis Systems

Atlantic Consulting Economics Limited

Atlas Construction Company

Auburn Equipment Contractors Incorporated

A.C.A. Howe International

B

Bacon-Donaldson

Bay Mills Limited

B (cont'd)

Bechtel of Canada Limited

Bertrand and Frère Construction

BM Hi-Tech

BNR-Northern Telecom

Bondar-Clegg Limited

Boston Bay Resources

BP Research Centre

Bruni Water Works Inc., Texas

Brunswick Mining and Smelting

B.P. Selco

C

Canada Brick

Canada Cement Lafarge

Canada Tungsten Mining Corporation Limited

Canadian Electrolytic Zinc

Canadian Gold Centrifuge

Canadian Industries Limited (CIL)

Canadian Lencourt Mines

Canadian Liquid Air

Canadian Portland Cement Association

Canadian Society of Civil Engineering (CSCE)

Canadian Steel Foundry

Canamax Resources Incorporated

C (cont'd)

Canberra Packard Canada

Caribou New Brunswick Mining Limited

Central Canada Potash

Centre de Recherche Noranda

Centre du Québec de la Valerisation de la Biomass

Ceramics Kingston Incorporated

Chemtech, New York

Chevron Research Company

Chinese Non-ferrous Metals Industry Corporation

Chromasco

Comdale Technologies Incorporated

Cominco Limited

Concord Scientific Corporation

Coopers Lybrand

Curragh Resources

C. Farman, Consultant

D

Day and Associates

Delcan Canada Limited

Deloitte, Haskins and Sells

Denison Mines Limited

Denison Potocan Potash Company

DIPIX Systems Limited

D (cont'd)

Dome Mines

Domtar

Dupont Canada

Durand-Raute Industries Limited

Durham Mines Limited

D. Kuntze, Consultant

E

Echo Bay Mines Limited

Eggerding of Amsterdam

Eldor Mines Limited

Electrowatt Engineering Services Limited

ENGENICS Limited

Enterprise of Rare Metals, Romania

Envirosphere Consultants

Erco Industries Limited

Esso Resources

Exothermic Company Limited

Exploration Rambo Incorporated

F

Falconbridge Mines

Fenco Lavalin

F.C. Hume and Company

G

Galactic Resources Limited

General Communication

Geochemical Corporation

Geocon Limited

Geotechencia Y Cimientious

Giant Yellowknife Mines Limited

Globe and Mail

Gordex Minerals

Groupe Minier Morisco

Groupe-Conseil Roche Limite

H

Handy Chemicals

Hanna Mining Company

Harwill Technologies International Incorporated

Hatch and Associates

Hawker-Siddley (Orenda Division)

Heath Steele

Hollister Geological Consultants Limited

Hudson Bay Mining and Smelting Company Limited (HBMS)

I

Industrial Minerals Study Group

I (cont'd)

Interact Research and Development Corporation

Intercom Consultants

International Nickel Company of Canada Limited

Iron Ore Company of Canada (IOC)

IVACO Rolling Mills

J

Jacques Whitford Associates

J.M. Asbestos Incorporated

K

Kalium Chemicals

Kentucky Energy Cabinet Laboratory

Key Lake Mining Corporation

Kidd Creek Mines Limited

Kilborn Engineering

Klondike Placer Miner Association

Kratos Analytical Instruments

L

LAB Chrysotile

Laboratoire de Béton Limitée

Lakefield Research of Canada Limited

L (cont'd)

Lawrason Chemicals

Louvicourt Mining Management Company

M

Madeleine Mines Limited

Maghemite

Master Builders

Metallurgy and Associated Industries

Mitchum Explorations

Mobil Oil

MYCO (New York)

N

National Silicates

Neptune Resources Group

Newmount Exploration

Noranda Incorporated

Noranda Research Centre

Norbec Mill

Northern Telecom

Northgate Mines Incorporated

Nova Corporation

O

Omal Laboratories Limited

Opportunities Limited

Orocon Incorporated

Outokumpu Corporation

O'Mac Assay Laboratories, Ireland

P

Pancontinental Mining Limited, Australia

Penalta Management Association Incorporated

Phillips Barratt Kaiser

Placer-Dome Research

Platinum Lake Resources Incorporated

Pollutech Incorporated

Pollution Control and Industrial Hygiene

Potash Corporation of Saskatchewan

Pylon Electronic Development Company Limited

Q

QIT-Fer et Titane, Incorporé

Quebec Cartier Mining

Quebec Metal Mining Association

Queenstake Resources Limited

R

Ramsey REC Limited

Reiss Lime Company of Canada Limited

Relmech Manufacturing Limited

Resources Robex

Rio Algom Limited

Rohm and Haas Company

R. Siscoe, Mineral Processing Consultant

R. Swider, Consultant

S

Schwartzwalder Mines

Selbaie Mines

Selkirk Silica Limited

Serrener Consultation Incorporated

Sherritt Gordon

Sidbec-Dosco

Slater Steels Corporation

Steep Rock Resources Incorporated

Steetley Talc

Stelco Incorporated

Stellarton

Stewart Lake Iron Mines of Ontario Limited

Ste. Foy Consultants

S (cont'd)

Strathcona Mineral Services Group

St. Lawrence Cement Company

St. Mary's Cement

Sullivan Mines Incorporated

Suzorite Mica Resources

T

Techma Limited, New York

The Gorsline Company, USA

Timminco Metals

Trans Canada Pipelines Limited

Trojan Technologies Incorporated

Trow Limited

U

Umex Incorporated

Uniquartz Limited

United Engineers and Contractors

Utah Mines Limited

V

V. F. Hollister, Consultant

W

Witteck Development

PART F. PROFESSIONAL, TECHNICAL AND ADMINISTRATIVE STAFF

NAME	DEGREES	OCCUPATIONAL CATEGORY
Sirois, L.L.	B.A., B.Eng., (McGill); P.Eng.	Director MSL
Craigen, W.J.S.	B.Sc. (Queen's)	Phys. Sci.

ADMINISTRATION

Alexander, G.	Technologist
Bart, J.A.	Admin. Support
Bisson, S.	Admin. Support
Carbonetti, S.	Admin. Support
Deans, D.	Admin. Support
Desrochers, L.R.	Admin. Support
Emmerson, M.	Admin. Support
Groulx, P.	Admin. Support
Joly, A.	Admin. Support
Lamb, K.A.	Admin. Support
Lavallée, L.	Admin. Support
Lord, S.	Admin. Support
MacLeod, J.D.	Scientific Illustration
Mathurin, D.	Admin. Support
Palmer, M.	Admin. Support
Richer, P.	Technologist
Rochon, J.P.	Admin. Officer
Villeneuve, J.	Admin. Support

NAME	DEGREES	OCCUPATIONAL CATEGORY
CHEMICAL LABORATORY		
Steger, H.F.	B.Sc., Ph.D. (McMaster)	Manager
Guest, R.J.	B.Sc. (Acadia)	Asst. Manager Operations
Atkinson, J.E.	B.A. (Queen's)	Chemist
Barkley, D.J.	B.Sc. (Carleton)	Chemist
Carson, D.W.		Technologist
Charbonneau, R.		Technologist
Chénier, M.		Technologist
Churchill, T.R.	B.Sc. (Western Ontario)	Chemist
Cloutier, J.C.		Technologist
Craig, R.R.	B.Sc. (Glasgow)	Chemist
Cyfracki, E.		Technologist
Dalton, J.L.	B.Sc. (Manitoba); M.Eng. (Carleton); C. Chem.	Chemist
Desgagné, M.	B.Sc. (Laval)	Chemist
Desjardins, L.		Technologist
Donaldson, E.M.	B.Sc. (Manitoba)	Res. Sci.
Fortin, R.A.		Technologist
Graham, J.A.	B.Sc. (Carleton)	Chemist
Guibord, M.P.		Admin. Support
Guillas, R.J.		Technologist
Hole, J.C.	B.A. (Toronto)	Chemist
Horton, R.E.	B.Sc. (Carleton)	Chemist
Hunt, G.A.	B.Sc. (Carleton)	Chemist
Josling, C.A.		Technologist

NAME	DEGREES	OCCUPATIONAL CATEGORY
Lalande, J.L.		Lab. Support
Lalonde, C.R.		Technologist
Lalonde, R.C.	B.Sc. (Carleton)	Chemist
Leaver, M.E.	B.Sc. (Queen's)	Chemist
MacEachern, E.H.	B.Sc. (Mount Allison)	Chemist
McIntosh, D.G.		Tech. Support
McCorkell, R.H.	M.Sc., Ph.D. (Manitoba)	Chemist
McCulloch, L.		Technologist
Moloughney, P.		Technologist
Nelson, G.L.		Technologist
Palombo, D.P.		Technologist
Provencher, R.	B.Sc., M.Sc., Ph.D. (Sherbrooke)	Res. Sci.
Pugliese, R.J.		Technologist
Richardson, G.		Technologist
Sawchyn, M.N.		Technologist
Sheldrick, D.		Technologist
Smith, C.W.	M.Sc., Ph.D. (Queen's)	Res. Sci.
Townsend, M.G.	B.Sc., Ph.D. (Southhampton)	Res. Sci.
Tremblay, R.J.J.		Technologist
Varette, D.M.		Admin. Support
Westra, P.		Tech. Support
Wittwer, J.W.	B.Sc. (Carleton)	Chemist

NAME	DEGREES	OCCUPATIONAL CATEGORY
EXTRACTIVE METALLURGY LABORATORY		
Campbell, M.C.	B.Sc. (St. Francis Xavier) B.Eng. (N.S.T.C.), D.I.C., M.Sc. (London); P.Eng.	Manager
Ahmed, S.M.	B.Sc., M.Sc. Ph.D. (Saskatchewan)	Res. Sci.
Bedard, P.L.		Technologist
Bell, D.H.	B.A.Sc. (Toronto); Ph.D. (London); D.I.C. (Imperial College)	Phys. Sci.
Bowman, W.S.	B.Sc. (Carleton)	Technologist
Brannen, J.M.		Technologist
Carter, L.E.		Technologist
Chalykoff, C.	B.Sc. (Carleton)	Technologist
Davidson, G.R.	B.Sc. (Carleton)	Technologist
Deschênes, G.	B.Sc., M.Sc. (Laval)	Phys. Sci.
Dinardo, O.	B.Sc. (Carleton)	Phys. Sci.
Dutrizac, J.E.	M.A.Sc., Ph.D. (Toronto)	Res. Sci.
Gould, W.D.	B.Sc. (Manitoba); M.Sc. Ph.D. (Alberta)	Res. Sci.
Griffith, W.F.		Technologist
Hamer, C.	B.E. (N.S.T.C.), M.Sc. (Queen's); P.Eng.	Res. Sci.
Haque, K.E.	M.Sc., Ph.D. (Ottawa)	Res. Sci.
Hardy, D.J.		Technologist
Jasmin, D.		Admin. Support
Joly, M.		Tech. Support
Karwowska, R.	M.Sc., Ph.D. (Warsaw)	Technologist
Kearns, J.B.		Technologist

NAME	DEGREES	OCCUPATIONAL CATEGORY
La Forest, D.		Technologist
Laliberté, J.J.		Technologist
Liang, D.	B.Sc., M.Sc. (Queen's)	Engineer
Lucas, B.H.	B.Sc. (Queen's); P.Eng.	Res. Sci.
MacKinnon, D.J.	B.Sc., M.A.; Ph.D. (Ottawa)	Res. Sci.
McCready, R.G.L.	B.Sc., M.Sc. (Alberta); Ph.D. (Calgary)	Res. Sci.
McNamara, V.M.	B.Sc., B.Eng., M.A.Sc. (Toronto); P.Eng.	Res. Sci.
Mikhail, S.A.	B.Sc., Ph.D. (Cairo); Dr.Eng. (Norway)	Res. Sci.
Molnar, R.	B.Eng. (McGill); Ph.D. (Univ. of London); D.I.C.	Res. Sci.
Morrison, R.M.	B.Sc., Ph.D. (UBC)	Res. Sci.
Paquette, L.A.		Admin. Support
Pilgrim, R.F.	B.Sc. (Queen's)	Res. Sci.
Pouskouleli, G.	B.Sc. (Aristotelian Univ., Greece); M.Sc. (Université de Montréal); Ph.D. (McGill Univ.)	Res. Sci.
Prud'homme, P.J.A.		Technologist
Rajan, S.		Technologist
Ritcey, G.M.	B.Sc. (Dalhousie)	Res. Sci.
Rolko, V.H.E.	B.Sc. (Manitoba)	Chemist
Roxburgh, N.B.		Technologist
Salley, J.	B.Sc. (Ottawa)	Phys. Sci.
Sanmugasunderam, V.	B.Sc. (Univ. of Ceylon); M.Sc. (Univ. of Wales); Ph.D. (UBC)	Res. Sci.

NAME	DEGREES	OCCUPATIONAL CATEGORY
Shimano, D.Y.	B.Sc. (Concordia)	Phys. Sci.
Skeaff, J.M.	B.Sc., M.Sc., Ph.D. (Toronto)	Res. Sci.
Sunstrum, J.		Admin. Support
Sutarno, R.	B.E., M.E., Ph.D. (N.S.T.C.); P.Eng.	Res. Sci.
Tan, K.G.	M.Sc.Chem. (Univ. of Aachem, Germany); Ph.D. (Carleton)	Res. Sci.
Taylor, J.B.		Technologist
Tremblay, G.	B.Eng. (Civil) (Carleton)	Phys. Sci.
Turcotte, A.M.		Technologist
Wallingford, G.		Technologist
Weatherell, C.	B.Sc. (Waterloo)	Chemist
Webster, A.H.	B.A., M.A., Ph.D. (UBC)	Res. Sci.
Wong, E.W.		Technologist
Wilson, L.J.	B.Sc. (McMaster)	Phys. Sci.

MINERAL PROCESSING LABORATORY

Campbell, F.R.	Eng. D. (St. Francis Xavier); B.Eng. (N.S.T.C.); Ph.D. (London); D.I.C. (Imperial College)	Manager
Aota, J.	M.Sc. (UBC)	Phys. Sci.
Ahmad, A.	B.Sc., M.Sc., Ph.D. (New Brunswick)	Res. Sci.
Andrews, P.R.A.	B.Sc. (London); M.Eng.Sc. (Melbourne)	Res. Sci.
Beaulne, J.M.		Technologist
Besso, K.M.	B.Sc. (Montreal)	Phys. Sci.
Bilodeau, A.	B.Sc. (Laval)	Engineer

NAME	DEGREES	OCCUPATIONAL CATEGORY
Bilodeau, M.	B.Sc. (Laval)	Phys. Sci.
Boisclair, M.		Technologist
Brearley, G.D.		Technologist
Cabri, L.J.	B.Sc., M.Sc., Ph.D. (McGill)	Res. Sci.
Cameron, W.H.	B.Sc. (Queen's)	Phys. Sci.
Campbell, R.B.		Technologist
Canaday, J.D.	M.BA (Univ. of Arizona); B.Sc. (Univ. of Oklahoma); M.Sc. (Univ. of Calgary); M.Sc., Ph.D. (Univ. of Guelph)	Res. Sci.
Carette, G.G.	B.Sc. (Laval)	Eng.
Carrière, P.		Technologist
Chen, T.T.	B.Sc., M.Sc., Ph.D. (Cornell)	Res. Sci.
Chevrier, R.		Technologist
Childe, C.H.	B.Sc. (McGill)	Technologist
Chow, M.		Admin. Support
Cienski, T.	B.A. (Poland)	Phys. Sci.
Cimon, D.	B.Sc., M.Sc. (Laval)	Phys. Sci.
Collings, R.K.	B.Eng. (N.S.T.C.); P.Eng.	Res. Sci.
Cristovici, M.	B. Mining and Metallurgical Eng. (Bucharest); P.Eng.	Res. Sci.
Douglas, E.	B.Sc. (Chem. Eng.) (Argentina); Ph.D. (McGill)	Res. Sci.
Doyle, D.M.	B.Sc. Min. Eng. (Michigan Technical Univ.)	Phys. Sci.
Feasby, D.G.	B.Sc., M.Sc. (Queen's)	Phys. Sci.
Hanson, A.J.		Technologist

NAME	DEGREES	OCCUPATIONAL CATEGORY
Hinsperger, C.J.		Tech. Support
Hughson, M.R.	B.A. (Western Ontario)	Phys. Sci.
Jambor, J.L.	B.A., M.Sc., Ph.D. (Carleton)	Res. Sci.
Joly, T.		Admin. Support
Kelly, W.M.		Technologist
Kuriakose, A.K.	B.Sc., M.A., Ph.D. (Madras, India)	Res. Sci.
Lacelle, L.		Tech. Support
Laflamme, J.H.		Technologist
Laguitton, D.	Chem. Eng. (Rennes); D.Sc. (Laval)	Res. Sci.
Lamothe, J.M.	B. Mining Eng. (Ecole Polytechnique Montreal)	Engineer
Lavallée, M.	B.Eng. Mining (McGill)	Phys. Sci.
Legault, C.		Admin. Support
Leigh, G.		Technologist
Lemieux, G.		Technologist
Leung, J.H.C.	B.Sc. (Taiwan); M.Sc. (Waterloo)	Phys. Sci.
Loucks, N.D.		Admin. Support
Mainwaring, P.R.	B.Sc. (UWO); Ph.D. (Toronto)	Res. Sci.
Malhotra, V.M.	B.Sc., B.E. (W. Australia)	Res. Sci.
Mathieu, G.I.	B.A., B.Sc. (Laval)	Res. Sci.
McDonald, A.G.		Technologist
Mirkovich, V.V.	Ph.D. (Toronto)	Res. Sci.

NAME	DEGREES	OCCUPATIONAL CATEGORY
Moon, K.S.	B.Sc. (Seoul National Univ.); M.A.Sc. (UBC); Ph.D. (Berkeley)	Res. Sci.
Morin, L.		Technologist
Owens, D.R.		Technologist
Painter, K.E.	B.Sc. (Carleton)	Technologist
Petruk, W.	B.Eng., M.Sc., Ph.D. (McGill)	Res. Sci.
Pinard, R.G.		Technologist
Prud'homme, P.J.H.		Technologist
Quon, D.H.H.	B.Sc. (National Sun Yat Sen U); M.Sc. (Ohio State); Ph.D. (Michigan)	Res. Sci.
Raicevic, M.		Technologist
Reynolds, V.G.	B.Sc. (Carleton)	Phys. Sci.
Rouleau, J.P.		Tech. Support
Scharf, R.I.		Technologist
Sivasunderam, V.	B.Sc. (Srilanka); M.Sc. (Massachusetts)	Phys. Sci.
Soles, J.A.	B.A.Sc., M.A.Sc. (British Columbia); Ph.D. (McGill); P.Eng.	Res. Sci.
Stefanski, M.	B.Sc., M.Sc., Ph.D. (Katowce); Ph.D. (Krakow)	Phys. Sci.
Stemerowicz, A.I.	B.Sc. (Queen's); P.Eng.	Res. Sci.
Szymanski, J.T.	B.Sc., Ph.D. (London)	Res. Sci.
Venturino, M.		Admin. Support
Wang, S.S.B.	B.Sc. (Hong Kong Baptist); M.Sc. (California); Ph.D. (Toronto)	Phys. Sci.

NAME	DEGREES	OCCUPATIONAL CATEGORY
Wilson, H.S.	B.E. (Saskatchewan)	Res. Sci.
Wilson, J.M.D.	B.Sc., M.A.Sc. (Queen's)	Phys. Sci.